OFFSHORE POWER SYSTEMS
8000 Arlington Expressway
Jacksonville, Florida 32211

SELF-SHIELDED FLUX CORED WIRE EVALUATION

FINAL REPORT
DECEMBER 1980

Project Manager:
T. E. Bahlow

Principal Investigator:
A. W. Johnson

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FOREWORD

The purpose of this report is to present the results of a research and development program which was initiated by the members of the Ship Production Commnittee of the Society of Naval Architects and Marine Engineers and financed largely by government funds through a cost-sharing contract between the U.S. Maritime Administration and Bethlehem Steel Corporation. The effort of this project was directed to the development of improved methods and hardware applicable to shipyard welding in the United States.

Mr. w. c. Brayton and Mr. F. X. Wilfong of Bethelhem Steel Corporation were Prcgram Managers, Mr. T. E. Bahlow of Offshore Power Systems was Project Manger, and Mr. A. W. Johnson of Offshore Power System was the Principal Investigator.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee the served as techncal advisors in the preparation of inquiries and evaluation of subcontract proposals.

ABSTRACT

Representative self-shielded flux cored wires were evaluated to determine their chemical, mechanical and toughness properties over a range of heat inputs, their operator appeal in an optimum parametric mode and their rates of deposition in comparison with low hydrogen, iron powder conventional electrodes. During the course of evaluation, a screening phase was conducted to establish the self-shielded flux cored wires of supsrior mechanical/toughness properties and operator appeal. For the superior filler materials, a more extensive mechanical and toughness evaluation was conducted. For all wires evaluated, chemical and mechanical properties in general were satsifactory. Several wires were additionally found to exhibit excellent toughness properties at both upper and lower shelf regions. Operator appeal for certain self-shielded wires was found promising germane to shipbuilding adaptability. Deposition rates of the self-shielded family of wires was found to be extremely attractive from a cost effective stand point as compared with conventional electrodes. Recommendations for future evaluations were presented.

SELF-SHIELDED FLUX CORED WIRE EVLUATION

1.0 INTRODUCTION

Self-shielded flux cored welding potentially offers many advantages and economic benefits to the shipbuilding industry. Productivity and overall cost effectiveness can be enhanced by a process that emulates the characteristics of traditional shielded metal-arc welding (SMAW).

2.0 BACKGROUND

SMAW is characterized by its simplicity, versatility, and flexibility and as a result has found a vast acceptance in the shipbuilding industry. SMAW, like all welding processes however, is not utopian and has certain cost effective shortcomings relative to productivity. As a means of affording improved productivity measures such as increases in arc time and deposition rates, manufacturers for some time have researched and produced various wire formulations for the self-shielded flux cored welding (FCAW) process that emulates SMAW.

In the early years of wire development, self-shielded flux-core welding was viewed as an unattractive option in applications requiring high quality production welds. The majority of welding engineers perhaps associated the many problems of these wires with the way in which the product was produced by the manufacturers. The manufacturers realized their products had pitfalls, as evidenced by their assurances to the welding industry that yet another formulation would soon be avilable. Today, however, the tide has reversed to the extent that certain manufacturers boast of the state-of-the-art weld quality levels achievable with self-shielded flux cored wires. If adaptive in a shipbuilding environment, the potential benefits of a self-shielded flux-cored wire process which increases productivity while minimizing the moisture pick-up problems of low-hydrogen electrodes are quite obvious.

3.0 PROJECT OBJECTIVES

The primary objectives of this project are to evaluate the state-of-the art adaptability of gasless flux cored wire to the shipyard environment, and to evaluate the deposited weld metal mechanical and toughness properties.

A secondary project objective is to provide a measure of process cost effective evaluation via a deposition rate comparison between gasless flux cored wires and E7018 electrodes in the flat and vertical positions.

4.0 EVALUATION PLAN

To achieve the project objectives, a manufacturers literature survey was conducted to select six (6) commercially available self-shielded flux cored wires. The survey attempted to select a representative number of manufacturers and those candidate wires potentially attractive from a user's adaptive and a wire mechanical/toughness property viewpoint. The survey revealed that only two manufacturers published notch toughness data on but a few of their products and two other major suppliers withdrew their gasless wires from the market. Additional wire manufacturers offered that notch toughness properties for their self-shielded wire(s) would be expectedly low. From the survey, the following wires were felt to be representative and were selected for evaluation:

o Airco Selfshield 4, 3/32", E70T-4, DCRP
A new flat position product for the user concerned primarily with high deposition rates; no notch toughness properties are advertised for this product.

o Hobart Fabshield 8, 3/32", E70T-G, ZCSP
An all position wire with notch toughness properties advertised.

0 Hobart Fabshield 8Ni, 3/32", E70T-G, DCSP
   An all position electrode containing 2% nickel with good notch toughness properties typically reported.

o Lincoln NR302, 3/32", E70T-G, DCRP
   A high deposition rate flat position wire with notch toughness data typically reported.

o Lincoln NR203M, 3/32", E70T-G, DCSP
   An all position wire with excellent notch toughness data typically reported.

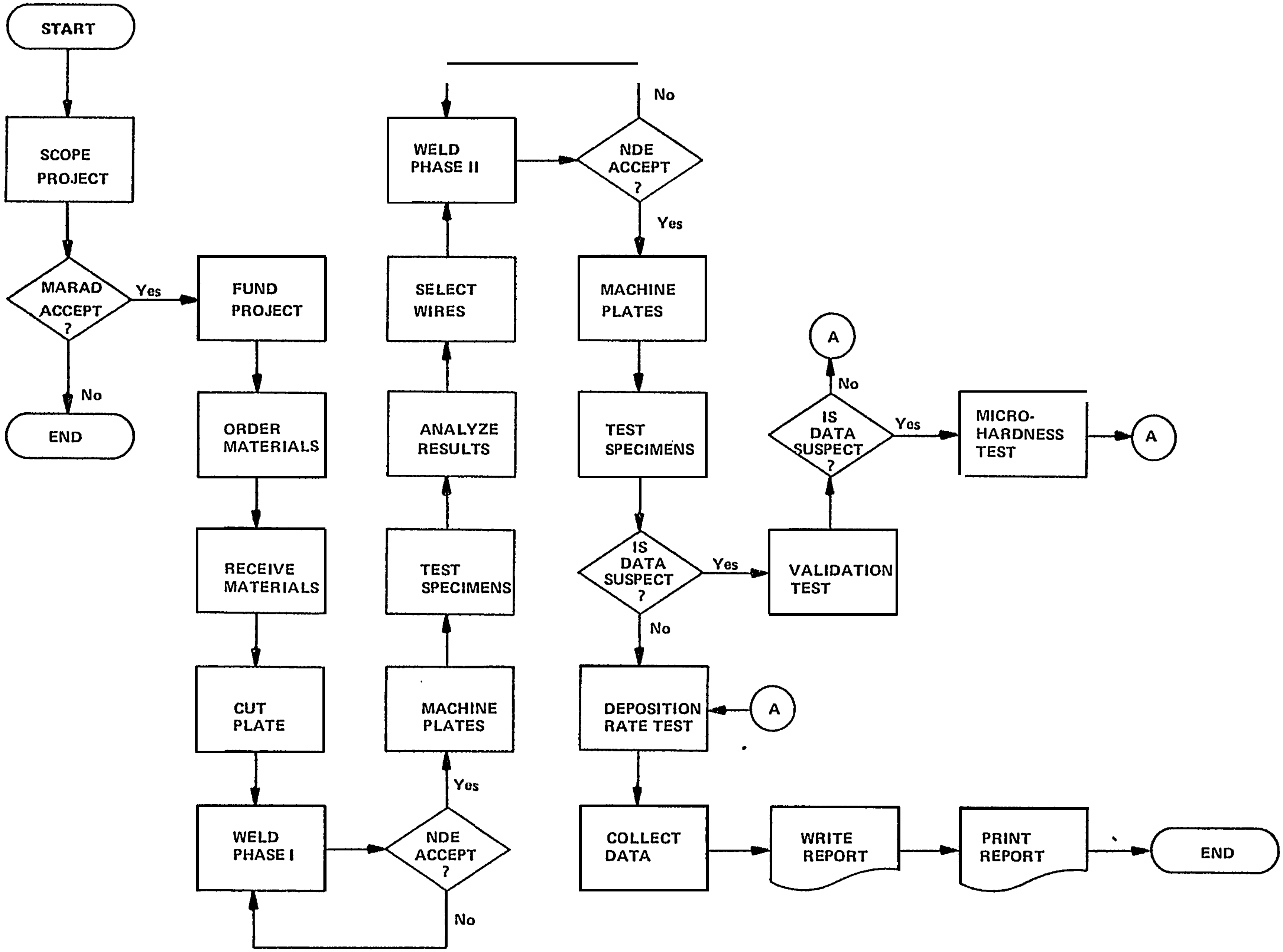
o Lincoln NR203Ni, 3/32", E70T-G, DCSP
   An all position electrode producing a 1% nickel deposit with excellent notch toughness properties advertised by the manufacturer.

The base material selected for this evaluation program was 3/4" ASTM A-36 plate with 3/8" ASTM A-36 backing. As only weld centerline properties were planned for investigation, actual base material mechanical and chemical properties were considered non-essential and were therefore not evaluated.

Following wire selection, a program, as displayed in Figures 1 and lA, was developed for comprehensive wire evaluation. The evaluation plan categorized the project into the following distinct ***phases:***

o PHASE I - A screening phase to identify those wires of superior performance germane to operator appeal and toughness property characteristics.

o PHASE II - A final evaluation phase to develop full mechanical and toughness property data for the superior Phase I wires over a range of heat inputs.



PROJECT FLOW CHART

FIG. 1

MANUFACTURER WIRE NAME	KJ/IN	MECHANICALS TEN	MECHANICALS Y	MECHANICALS %EL	MECHANICALS %RA	TOUGHNESS CVN	TOUGHNESS DT	TOUGHNESS DW	WELD METAL CHEMISTRY	OPERATOR APPEAL	VALIDATION TEST CVN	VALIDATION TEST DT	VALIDATION TEST DW	MACRO HARD(K) CVN	MACRO HARD(K) DT	MACRO HARD (R15T) CVN	MACRO HARD (R15T) DT	MICRO PHOTOS	DEPOSITION RATE FLAT	DEPOSITION RATE VERT.
PHASE I																				
AIRCO SNELFSHIELD 4	35	●	●	●	●	●	●	●	●	●										
HOBART FAUSHIELD 8	35	●	●	●	●	●	●	●	●	●										
NOBART FABSNIELD 8N1	35	●	●	●	●	●	●	●	●	●										
LINCOLN NR 302	35	●	●	●	●	●	●	●	●	●										
LINCOLN NR 203M	35	●	●	●	●	●	●	●	●	●								●		
LINCOLN NR 203 Ni	35	●	●	●	●	●	●	●	●	●										
PHASE II																				
HOOBART FABSHIELD 8Ni	50	●	●	●	●	●	●	●												
	65	●	●	●	●	●	●	●	●					●		●				
	80	●	●	●	●	●	●	●												
LINCOLN NR 302	50	●	●	●	●	●	●	●												
	65	●	●	●	●	●	●	●	●					●		●		●		
	80	●	●	●	●	●	●	●												
LINCOLN NR 203M	50	●	●	●	●	●	●	●						●	●	●	●	●		
	65	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●		
	80	●	●	●	●	●	●	●						●	●	●	●	●		
LINCOLN NR 203 N1	50	●	●	●	●	●	●	●												
	65	●	●	●	●	●	●	●	●					●		●		●		
	80	●	●	●	●	●	●	●												
PHASE III																				
LINCOLN NR 203M																			●	●
LINCOLN NR 302																			●	●
E7018 3/32"																			●	●
E7018 1/8"																			●	●
E7018 5/32"																			●	●
E7018 3/16"																			●	●

OVERALL VIEW OF THE WORK ACCOMPLISHED IN THE GASLESS FLUX CORE PROJECT **FIGURE 1A**

- o PHASE III - A deposition rate comparison between all position and flat position self-shielded flux cored wires and E7018 low hydrogen electrodes.

4.1 PHASE I

The Phase I evaluation plan was developed to provide an initial screening of those self-shielded flux cored wires that appeared to offer the maximum potential for shipbuilding usage from an operator appeal, mechanical property and toughness property standpoint. It was felt that by imposing a constant welding condition of low heat input and arc parameters in accordance with manufacturers recommendations that a uniform comparison of all six (6) Phase I wires could be made.

The evaluation plan for each of the Phase I self-shielded flux cored wires was structured to evaluate the following specific attributes:

- o Adaptability
- o Operator Appeal
- o Deposited Chemistry
- o All-Weld-Metal Tensile Properties
- o Charpy V-Notch (CVN) Properties
- o Dynamic Tear (DT) Properties
- o Drop Weight (DW) NDTT Properties

4.2 PHASE II

The Phase II evaluation plan was established to provide a basis for an in-depth analysis of the most premising self-shielded flux cored wires as determined by Phase I evaluation. The Phase II program was structured to provide a detailed measure of deposited wire properties over a range of operating heat inputs and test temperatures. It was additionally anticipated that by minimizing the number of controlled weld process variables throughout Phase II, a maximum number of data conclusions could be realized.

The following attributes were established for Phase II evaluations:

- o Deposited Chemistry
- o All-Weld-Metal Tensile Properties
- o Charpy V-Notch (CVN) Properties
- o Dynamic Tear (DT) Properties
- o Drop Weight (DW) NDTT Properties
- o Weld Metal Microstructure

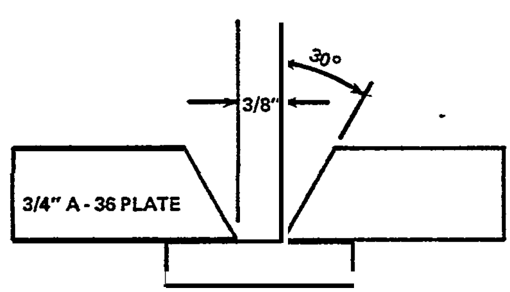
4.3 PHASE III

In the interest of productivity, Phase III was established to provide a comparison between the deposition rates of self-shielded flux cored wires and low hydrogen E7018 electrodes. An all position DCSP wire (Lincoln NR203M) and a flat position DCRP wire (Lincoln NR 302) were selected to provide this comparative measure.

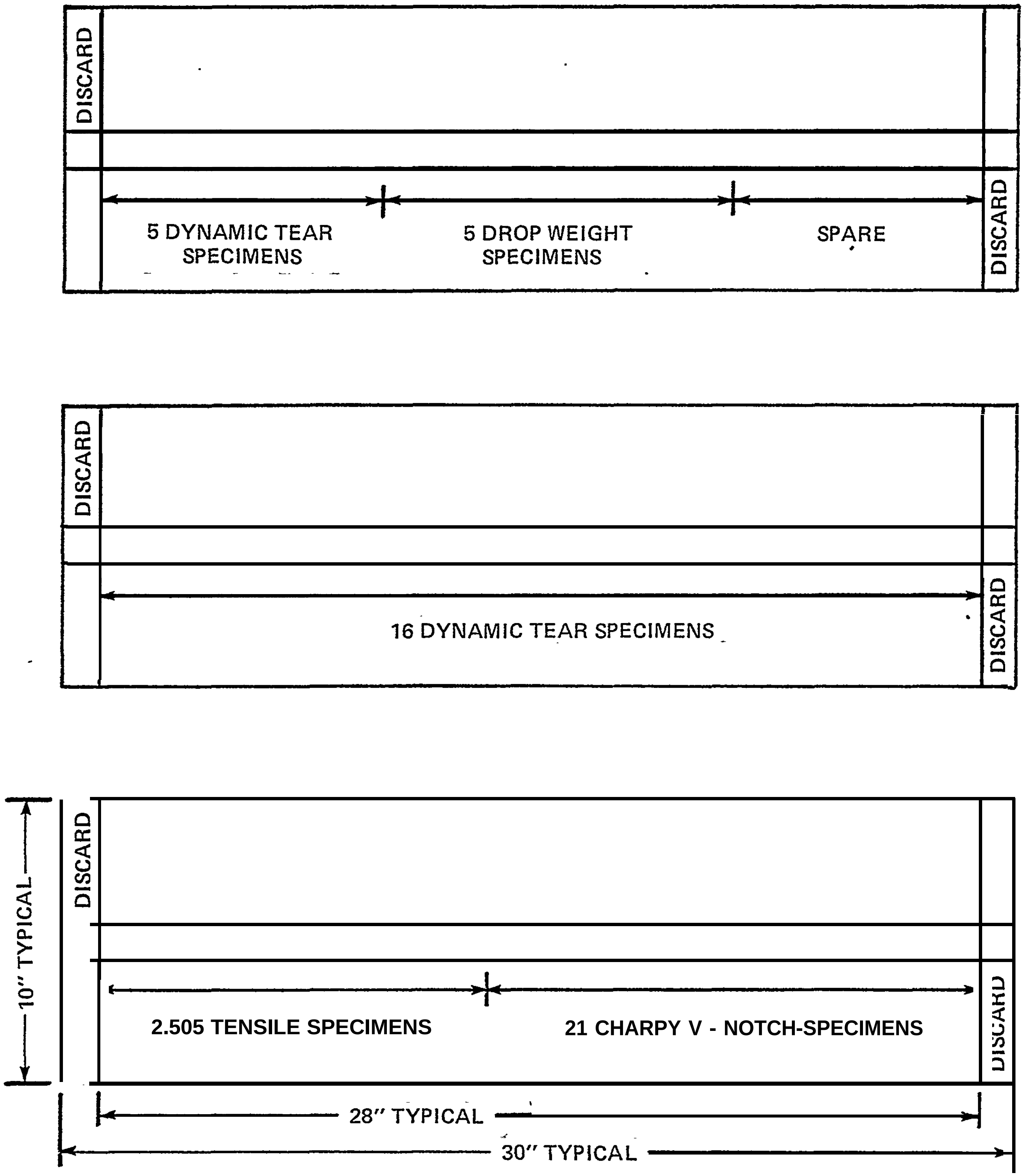
5.0 PHASE I EVALUATION PROCEDURE & TEST RESULTS

5.1 EVALUATION PROCEDURE (PHASE I)

The execution of Phase I was initiated with the procurement of 3/4″ ASTM A-36 carbon steel base material. The A-36 material was prepared by flame cutting into multiple 5″ X 30″ test plates with "feather edge" 30° bevel angles to conform to the backing strap joint shown in Figure A. To produce the required number of mechanical test specimens, three (3) 30" weldment assemblies were prepared for each wire evaluation test group in accordance with Figure 2. Each weld joint, adjacent area, and backing strap was shot-blasted prior to assembly for welding.



JOINT GEOMETRY FIG. A



TEST SPECIMEN LAYOUT OF WELDED ASSEMBLIES FIG. 2

All test assemblies were tack welded, strong backed and welded in the flat position. The 60° single-vee backing strap joint was selected to provide sufficient joint cross-section for subsequent all-weld metal. evaluation. All weldirg was conducted via side beam carriage operation with a constant voltage (CV) power supply to enable electrode stick-out, arc voltage, amperage, travel speed" and resultant heat input to be maintained constant throughout each given test group. All test assemblies were welded with a 30° lead angle technique at 35,000 joules/inch. Specific parameters for each Phase I wire evaluated are given in Table 1.

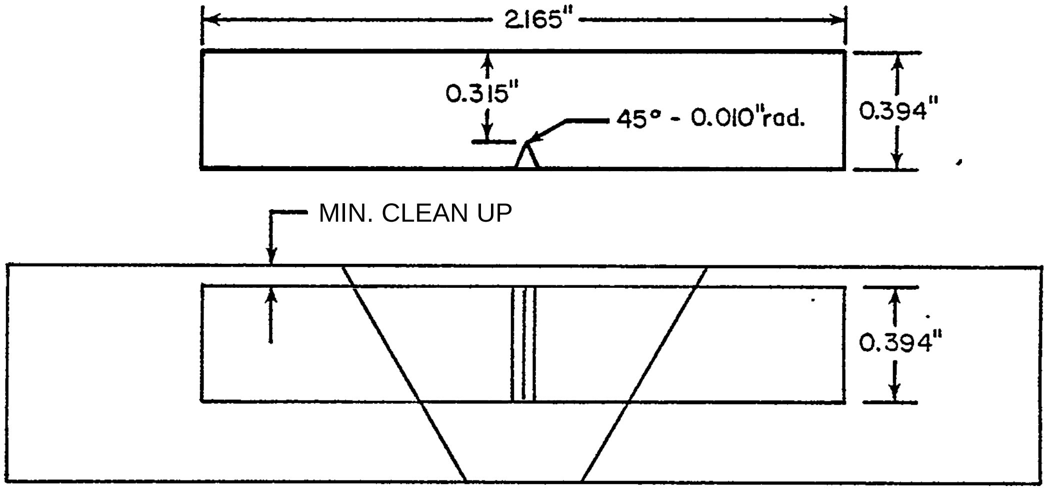
Following welding, each Phase I wire test group was subjected to the following testing criteria:

o Nondestructive Testing - Each weldment received 100% radiographic and. visual examination in accordance with ASME Section III, Section VIII, and ANSI B31. 1 requirements.

o Chemical Analysis - Four layer chemical analysis pads for each wire were made in the flat position. The undiluted deposited weld metal results were obtained by averaging three burns with a Baird-Atomic Spectrovac II, Model SM-1.

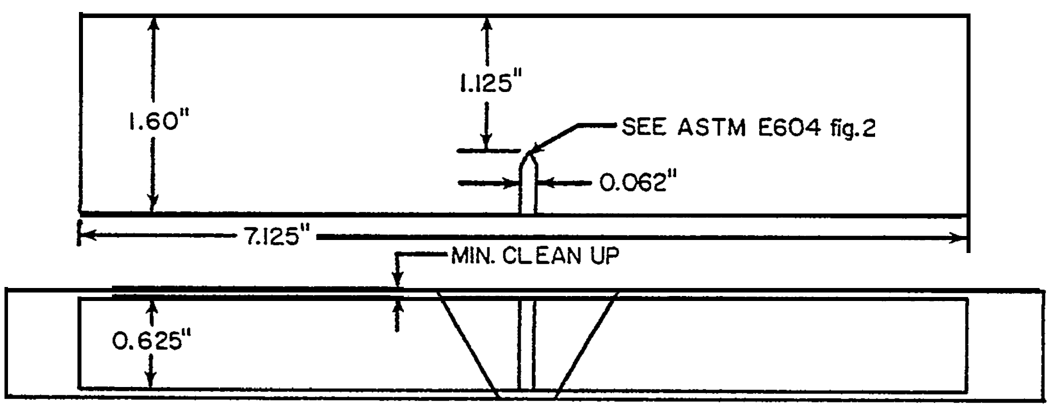
0 Mechanical Properties - For testing purposes, two .505 all weld metal tensile specimens were prepared in accordance with ASME Section IX, Part QW-462.1 (d). Testing was performed in accordance with AYTM E8 with tensile and yield strength, percent elongation, and percent reduction of area reported. This testing was performed with a Satec 400 WHVP tensile machine with a capacity of 400,000 Ibs. An extensometer Model PS5M was used in conjunction with this apparatus.

0 Notch Toughness Properties - Chary V-notch (CVN) and dynamic tear (UT) tests were performed and full temperature range transition data were developed. A total of twenty-one (21) specimens were



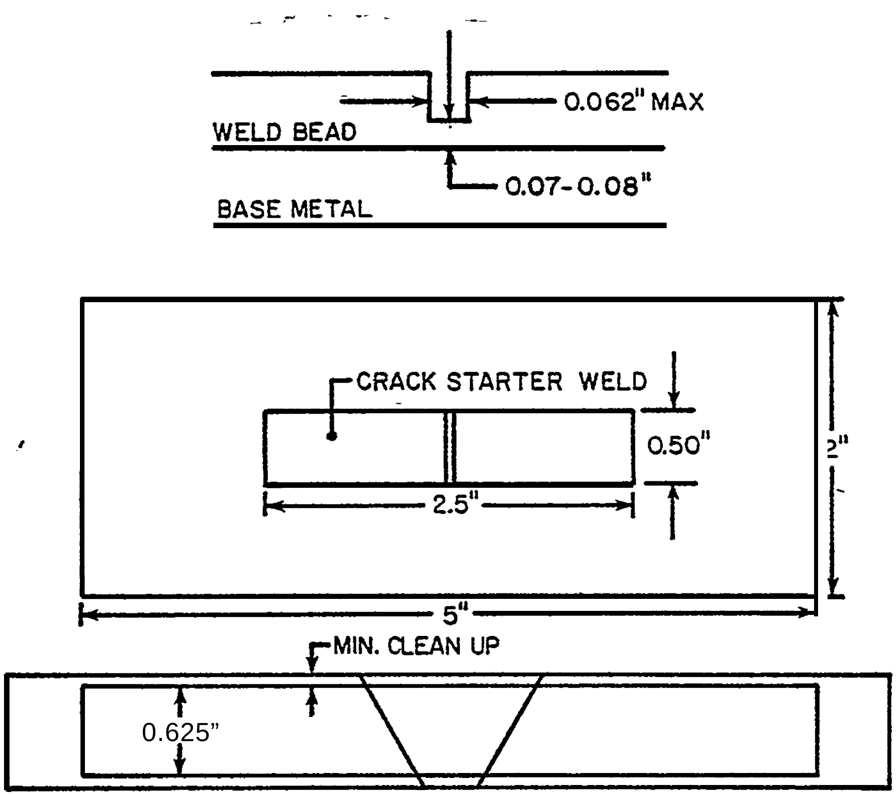
CHARPY V-NOTCH SPECIMEN AND LOCATION	FIG. B

evaluated at seven (7) temperatures from +100°F to -100°F for both toughness tests. ASTM E23 conformance was used in testing CVN specimens using Timius Olsen Model 64 equipment. A Dynatup Model 800D was used for DT specimens in accordance with ASTM "Proposed Method for 5/8" Dynamic Tear Test of Metallic Materials".



DYNAMIC TEAR SPECIMEN AND LOCATION	FIG. C

o **Nil Ductibility** Transition Temperature (NDTT) - For each of the gasless flux cord wires evaluated in Phase I, drop weight (DN) testing was employed to establish the deposited weldmetal NDTT. These specimens were prepard and tested following the guidelines set forth in ASTM 114 E208 using satec Model DW-30 equipnent.



DROP WEIGHT SPECIMEN AND LOCATION — FIG. D

o **Metallography** - A specimen from each Phase I test group was prepared for macrophotography.

5.2 TEST RESULIS AND DISCUSSION OF DATA (PHASE I)

5.2.1 Chemical and Mechanical/Toughness Properties

The chemical and mechanical Phase I test results are displayed in Tables 3 and 4 respectively. Notch toughness results for Charpy V-Notch (CV), dynamic tear (DT) and drop weight (DW) testing are given in Table 5. The notch toughness data is additionally displayed graphically in Figures 3 through 8 for CV and in Figures 9 through 14 for DT.

As previously noted, the self-shielded flux cored wires evaluated in Phase I are inherently quite different. The Airco Selfshield 4, for example, is classified as an AWS E70T-4 reverse polarity *wire* and requires a long electrical stick-out to obtain optimun arc transfer. The remaining five (5) wires are all classified E70T-G with an unspecified range of deposited weld chemistry. Of these E70T-G wires, only the Lincoln NR302 is a reverse polarity type and requires a short electrical sitck-out for optimum operation. In comparing the two reverse polarity wires; Selfshield 4 and NR302, the Airco wire was found to produce a deposited chemistry of very high carbon and very low manganese content. The carbon equivalent (CE) of the Airco product was observed to be slightly higher than that of the Lincoln NR302. Predictably, as shown in Table 5 and also in Figures 3, 6, 9, and 12, in comparison, the NR302 exhibited superior notch toughness properties.

Hobart Fabshield 8 and Lincoln NR203M are straight polarity (DCSP) wires of very similar operating parameters. In chemical comparison, however, the Fabshield 8 deposit contained nearly double the carbon and manganese levels found with NR203M. As expected, the tensile and yield properties of Fabshield 8 were observed to be substantially higher than those of NR203M, while elongation and reduction of area were observed to be lower. The notch toughness properties displayed in Table 5 and in Figures 4, 7, 10, and 13 clearly show the NR302 toughness superiority, partitularly at upper shelf regions.

The remaining two (2) E70T-G straight plarity (DCSP) self-shielded flux cored wires of Phase I are nickel additive. Hobart Fabshield 8Ni and Lincoln NR203Ni display camparable carbon equivalent values but contain 2% and 1% nominal nickel respectively. Fabshield 8Ni yielded superior tensile and yield properties but lower elongation and reduction of area. As indicated in Table 5 and in accompanying Figures 5, 8, 11, and 14, NR203Ni exhibited superior CV performance but very comparable DT and NDTT values. These nickel additive wires, as expected, exhibited superior lower shelf region notch toughness properties.

5.2.2 Adaptability and Operator Appeal (Phase I)

The results of the adaptability and operator appeal evaluation for Phase I wires are given in Table 2. The overall subjective wire ratings were found to range from fair to good with various wires warranting high marks in several rating categories.

As delineated in Table 2, the operator appeal evaluation rated numerous Phase I wire attributes either poor (1.0), fair (2.0), good (3.0) or excellent (4.0). From a composite rating for each wire, the test results in order of decreasing superiority are:

o Lincoln NR203M (3.3)
o Lincoln NR203Ni (3.0)
o Airco Selfshield 4 (2.9)
o Hobart Fabshield 8Ni (2.5)
o Lincoln NR302 (2.3)
o Hobart Fabshield 8 (2.1)

The operator appeal evaluation is an attempt to provide some subjective measure of how self-shielded wires potentially may be adapted to a shipbuilding environment. The evaluation indicates that there are wires on the market that exhibit good operating performance and therefore offer adaptability potential.

5.2.3 Summation of Results (Phase I)

In analyzing the overall mechanical properties, notch toughness properties and operator appeal results of Phase I, several wires exhibited superior performance. The Lincoln NR203M and NR203Ni wires were found to display high operator appeal and excellent notch toughness properties over a wide range of test temperatures, particularly at upper shelf regions. The Hobart Fabshield 8Ni and the Lincoln NR302 wires exhibited good mechanical property results with satisfactory toughness and operator appeal.

The Hobart Fabshield 8, although yielding good mechanical property results, fell short in both toughness and operator appeal. The Airco Shelfshield 4, a wire of good operator appeal, was inferior from a toughness standpoint.

In a composite review of all Phase I test results, considering mechanical properties, notch toughness properties and operator appeal, the following wires were selected for further in-depth Phase II evaluation.

- Lincoln NR203M
- Lincoln NR203Ni
- Hobart Fabshield 8Ni
- Lincoln NR302

6.0 PHASE II EVALUATION PRCEDURE AND TEST RESULTS

6.1 EVALUATION PROCEDURE (PHASE II)

The criteria for the execution of Phase II evaluation was identical to that of Phase I in most respects. ASTM A-36 base material prepared to a “feather edge”, backing strap configuration was employed for all weld test assemblies (Figure A). All welding was conducted in the flat position via side beam carriage operation with a constant voltage (CV) power supply.

The notable procedural difference between Phase II and phase I was heat input. To provide a measure of weld metal performance and property variation as a function of heat input, each Phase II wire was welded and evaluated at 50, 65, and 80 kilojoules/inch. Progressive increases in heat input were obtained by varying only the travel speed parameter for each wire. It was felt that by holding amperage and arc voltage essentially constant throughout Phase II, resultant chemistry variations would be minimized and a maximum number of data correlations would be possible. The parametric variables used in Phase II evaluation are given in Table 6.

Following welding, all test assemblies were radiographed to assure soundness. Chemical analysis was conducted from a 65,000 joules/inch test plate in accordance with the procedure employed in Phase I. Mechanical testing and notch toughness testing procedures in Phase II were identical to those employed in Phase I. Metallographic analysis of Phase II wires received greater attention and was directed at providing correlation of microstructure, microstructure and microhardness, to fracture toughness.

AS an additional means of evaluation, CVN and DT specimens tested at O°F were transversely sectioned immediately behind the fractured surface. These new specimens were subsequently polished and etched for macrophotographs, microstructure and microhardness evaluation.

The gasless flux cored wires selected for this evaluation and the respective heat inputs employed are “listed below.

o Lincoln NR 203M CVN specimens welded at 50, 65 and 80 K joules/ inch.

0 Lincoln NR 203M DT specimens welded at 50, 65 and 80 K joules/ inch.

o Hobard 8 Ni, Lincoln NR 203 Ni, and Lincoln NR 302 CVN specimens welded at 65 kilojoules/inch.

6.2 TEST RESULTS AND DISCUSSION OF DATA (PHASE II)

6.2.1 Deposited Chemistry (Phase II)

The as-deposited weld metal chemistry results are given in Table 7. In comparison with the results of Phase I, no appreciable chemistry differentials were observed.

6.2.2 Mechanical Properties (Phase II)

The Phase II all-weld-metal mechanical property results are summarized in Table 8. From the table, the following general correlation trend (with some exception) was observed:

- o As heat input increased:
  - o Tensile strength decreased
  - o Yield strength decreased
  - o Yield/Tensile ratio remained unchanged
  - o Ductility increased

The apparent tensile and yield decreases and ductility increases with increasing heat input is presumed to be the result of varying degrees of microstructural grain growth and refinement induced by repetitive heating and cooling cycles. In the case of one wire, Lincoln NR203M, the tensile strength obtained at the higher heat inputs of 65 and 80 kilo-joules/inch fell below 72,000 psi.

6.2.3 Notch Toughness Properties (Phase II)

The notch toughness CV, DT and DW results of Phase II are given in Table 9 and graphically presented in Figures 15 through 38. A considerable amount of notch toughness data was generated from the testing of weldments made from the four Phase II flux cored wires. Attempts to find correlations between CV and DT data were, however, unsuccessful when the different wires were compared. The unsuccessful correlation of CV and DT data led to an adjunct evaluation program to establish a larger notch toughness data base and validation of prior Phase II results. Lincoln NR203M was selected as the validation test wire and three (3) test plates were run at 65,000 joules/inch. Following radiography, 40 CV, 21 and 5 DW specimens were machined and tested. The results of this validation are displayed in graphic comparison with the NR203M original Phase II results in Figures 39 and 40. As delineated in Figure 39 the CV data of the validation test was found to represent an entirely different population than that originally established in Phase II. The DT and DW data, as shown in Figure 40, however, was found to be very comparable.

In analysis of the phase II notch toughness results of Table 9 and Figures 15 through 38, although CV and DT correlations were not apparent, impact values for the Lincoln NR203M and NR203Ni were excellent at the 50, 65 and 80 kilojoule/inch heat inputs. For both CV and DT these wires exhibited superior upper shelf, mid-energy and lower shelf properties. The NR203Ni, with 1% nominal nickel displayed a slightly lower DW nil-ductility transition temperature (NDTT), but in no instance fell above -60°F.

The Lincoln NR302 and Hobart Fabshield 8Ni displayed significantly lower CV and DT notch toughness properties than the Lincoln NR203M and NR203Ni wires. The NDTT, however, remained substantially low (-40°F to -60°F) for both wires with the-exception of NR302 at 50 kilojoules/inch (O°F).

A consistent trend to establish the effect of heat input fluctuation on notch toughness properties was not apparent. In most instances, however, a decrease in impact values was observed in progressing from heat inputs of 65 to 80 kilojoules/inch.

6.2.4 Metallographic Analysis (Phase II)

For metallographic evaluation, the test group listed below was representatively selected from fractured, parallel sectioned and polished/etched CV and DT specimens of Phase II.

o Lincoln NR203M CVN and DT. at 50 kilojoules/inch.
o Lincoln NR203M CVN and DT at 65 kilojoules/inch.
o Lincoln NR203M CVN and DT at 80 kilojoules/inch.
o Hobart Fabshield 8Ni CVN at 65 kilojoules/inch.
o Lincoln NR302 CVN at 65 kilojoules/inch.
o Lincoln NR203Ni CVN at 65 kilojoules/inch.

The results of metallographic analysis are displayed by macrophotographs and corresponding microhardness graphs in figures 41 through 49. In table form on each figure listed above is data for comparative purposes that contains the following information:

o Actual mechanical results from Phase II tensile specimens showing tensile, yield, % elongation, and % reduction of area.

o Hardness traverse across the face of the actual Weld macro showing Rockwell 15T average values and the corresponding tensile value.

o Hardness traverse across the pictured specimen showing average knoop and Rockwell 15T hardness values with corresponding tensile value.

0 Actual toughness values in ft/lbs of specimens tested at 0°F.

The microphotographs show substantial differentials in hardness associated with the layered or banded strata resulting from cyclic thermal heating and cooling. Because of the process dynamics, the variations in thermal cycles, and differences in the final locations of the original test specimens taken from the weldment, the macro and corre-spending microstructures *varied* considerably. The observed variations ranged from coarse and dendritic in as-welded final pass regions to recrystallized in intermediate and root pass regions to refined in intermediate and root pass regions subjected to multiple heating and cooling cycles. Examples of these structures are shown in figure 50. These microphotographs are taken from a macro specimen from Lincoln NR203M welded at 65 kilojoules/inch.

In reviewing the macrostructures, microstructures and their corresponding hardness data, the following general correlation trends were observed.

- 0 As grain size increases, hardness also increases, suggesting a corresponding decrease in ductility and toughness.

- o In progressing from weld root to weld face, increases in hardness suggest an increase in tensile strength and a corresponding decrease in ductility and toughness.

7.0 PHASE III EVALUATION PROCEDURE AND TEST RESULTS

7.1 EVALUATION PROCEDURES (PHASE III)

Phase III, a deposition rate comparative evaluation, was initiated by preparing and weighing A-36 plate material. Four diameters of E7018 electrodes (3/32″, 1/8″, 5/32″ and 3/16″) were welded in a bead-on-plate, flat position application for thirty seconds. The plates were reweighed and the resultant deposition rate in pounds/hour was calculated. To develop a deposition rate range, each electrode was run at various amperages within the manufacturers recommended minimum and maximum amperage. Appropriate diameters of E7018 electrode diameters were additionally run in the vertical position at various amperages to establish an optimum vertical-up range.

For comparative purposes, Lincoln NR203M, an all position DCSP wire, was selected for deposition rate evaluation. Two diameters, 5/64″ and 3/32″, were evaluted in the same manner as that employed for the SPAW electrodes. Lincoln NR302, a high deposition, flat position wire, was also run to establish an additional deposition rate comparative measure.

7.2 TEST RESULTS AND DISCUSSION OF DATA (PHASE III)

The results of this study are presented graphically in figures 51, 52 and 53. Figure 51 shows the comparisons of three (3) diameters of E7018 electrodes and two (2) diameters of all position (DCSP) gasless flux cored wires run in the flat position. This information is displayed for vertical welding in Figure 52. Figure 53 displays the deposition rates for SMAW electrodes, DCSP and DCRP (high deposition) gasless flux cored wires for comparative purpses.

The solid line in each graph depicts the tested range for each group or wire. The boxed portion of the line represents a suitable parametric range for each size and type as noted for flat and vertical welding. The dashed line displays the optimum amperage and correspending deposition rate as observed during actual welding.

A quick method for comparing electrodes, wires, and processes consists of reviewing the individual deposition rate data. For example, in vertical butt welding, a welder using an 1/8" E7018 electrode at 115 amps would deposit about 2.4 lbs/hr. With an operator factor of 25%, a net deposition rate of .6 lbs/hr would be expected. In using the gasless flux cored process with an all position wire for vertical welding, Figure 52 indicates that for a 5/64" diameter wire at 225 amps, a deposition rate of 4.25 lbs/hr would be anticipated. With an increase of only 10% operator duty factor to 35%, the net deposition rate would be approximately 1.5 lb/hr, representing a 150% increase in deposited metal. Even more impressive results are found by comparing the same diameter wire in the flat position at higher amerages.

The above illustrative example is given for comparative information only and net deposition rates will expectedly vary by individual facility and welding personnel capabilities. The example was used, however, to illustrate the attractive cost effective potential of self-shielded flux cored wires and to show a single diameter self-shielded wire could be used to potentially:

- o Minimize the procurred and inventoried multiple diameters of SMAW electrodes.
- o Increase the operating factor.

- o Increase deposition rates.
- o Increase travel speeds.

8.0 CONCLUSIONS

From the data collected as applied to the scope of this self-shielded flux core wire evaluation program the following general conclusions are drawn.

8.1 CHEMICAL, MECHANICAL AND TOUGHNESS PROPERTIES

8.1.1 Chemical - The wires evaluated are classified as either E70T-4 or E70T-G and deposited chemistry is therefore predominantly controlled not by specifications but by the manufacturer. Within the scope of this evaluation, it is concluded that the majority of wires tested yield favorable deposited wire chemistries. The Airco S-4 and the Hobart Fabshield 8 chemistries, however, appeared unfavorable from a carbon and manganese level standpoint. The S-4 wire with .221 deposited carbon and the Fabshield 8 wire with .149 carbon and 2.254 manganese appeared undesirable for any application requiring minimal toughness properties.

8.1.2 Mechancial Properties - The self-shielded wires tested exhibited good mechanical properties. Observed variations in deposited chemistry from wire to wire predictably yielded varations in tensile, yield, elongation and reduction of area. Within the limited population of this evaluation, the data revealed a general tensile and yield strength decrease at elevated heat input levels. From the data it is concluded that a minimum tensile of 72KSI and yield of 60 KSI would not consistently be achieved with the E70T-G wire family at elevated heat inputs.

8.1.3 Toughness Properties - Within the scope of this program, it was found that certain of the self-shielded flux cored wires evaluated exhibit excellent toughness properties as measured by charpy, dynamic tear and drop weight testing. Extremely high upper shelf charpy and dynamic tear properties were exhibited by the Lincoln NR203Ni and NR203M wires. At lower shelf regions, the charpy, dynamic tear and drop weight data at variable heat inputs were found to be widely varied and without correlation. The data, however, does reveal. that excellent lower shelf properties can be obtained by certain wires over a substantial heat input range. However, because of the limited evaluation sample size and the variable data collected, a conclusion that given wires would consistently yield excellent lower shelf properties cannot be supported.

8.2 OPERATOR APPEAL

For the family of wires evaluated, overall operator appeal was found to range between fair and good. The evaluation, which subjectively measured attributes such as slag removal, arc stability, weld spatter, bead appearance and wetting, found the Lincoln NR203Ni and NR203M wires to rank as the top composite performers.

8.3 RATE OF DEPOSITICN

In comparative analysis with conventional SMAW low hydrogen, iron powder electrodes, the self-shielded flux cored process was shown to exhibit substantial deposition rate superiority. It follows that overall process cost effectiveness is potentially quite attractive.

8.4 ADAPTABILITY TO SHIPBUILDING

Although this evaluation program was limited in scope and did not attempt to fully evaluate all attributes of self-shielded flux cored welding, the data obtained was encouraging for certain evaluated wires. In spite of the specification freedom allowed in manufacturing the E70T-4 and E70T-G wires, certain wires were found to exhibit excellent mechanical and toughness properties and good operator appeal. If property consistency from wire heat to heat can be varified, the deposition rate attractiveness of the process warrants attempts to implement certain self-shielded flux cored wires to appropriate shipbuilding production applications.

9.0 RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

The sample size of this evaluation was limited in that it dealt with minimal. heats of wire operating under controlled variable conditions. To gain an increased data bank of mechanical and toughness properties, the following evaluation additions are recommended for the more promising wires:

- Mechanical and toughness evaluation of multiple wire heats.

- Mechanical and toughness evaluation of multiple parametric variables such as arc length and amperage.

- Field evaluation to better determine cost effectiveness and operator appeal.

APPENDIX I

PHASE I

Tables & Figures

PHASE I PARAMETRIC VARIABLES TABLE 1

	Airco S-4	Hobart Fab 8	Hobart Fab 8 Ni	Lincoln 302	Lincoln 203M	Lincoln 203 Ni
Diameter	3/32"	3/32"	3/32"	3/32"	3/32"	3/32"
Polarity	RP	SP	SP	RP	SP	SP
Stick Out	2-3/4"	1"	7/8"	7/8"	3/4"	3/4"
KJ/IN	34.6	34.1	34.5	34.8	34.1	35.2
Amps	355	310	300	380	310	320
Volts	28	22	23	26	22	22
Travel IPM	17.5	12	12	17	12	12
No. of Passes	16/17	20/27	24/25	18/23	21/25	21/23

PHASE OPERATOR APPEAL TABLE 2

	Airco s-4	Hobart Fab 8	Hobart Fab 8 Ni	Lincoln 302	Lincoln 203M	Lincoln 203 Ni
Slag Removal	4	3	4	3	4	4
Spatter	2	1	3	2	4	3
Smoke	2	1	1	1	2	2
Bead Appearance	4	2	2	2	4	3
Bead Contour	4	2	2	2	3	3
Arc Stability	3	2	2	2	4	4
Soundness	2	3	3	3	4	3
Wetting	4	2	3	3	3	3
Cast, Helix	1	2	2	2	2	2
Odor	3	3	3	3	3	3
OVERALL RATING	2.9	2.1	2.5	2.3	3.3	3.0

KEY: 1.0 POOR 2.0 FAIR 3.0 GOOD 4.0 EXCELLENT

PHASE CHEMICAL RESULTS TABLE 3

	Airco S-4	Hobart Fab 8	Hobart Fab 8 Ni	Lincoln 302	Lincoln 203M	Lincoln 203 Ni
KJ/IN	34.6	34.1	34.5	34.8	34.1	35.2
c	.221	.149	.098	.097	.083	.094
Mn	.374	2.254	1.234	.850	1.457	1.354
P	.004	.016	.010	.000	.008	.006
Si	.070	.248	.184	.232	.209	.268
Ni	.012	.003	1.922	.028	.013	.800
Cr	.015	.015	.015	.016	.017	.023
Mo	.030	.048	.031	.046	.040	.037
Cu	.038	.014	.017	.014	.009	.009
s	.002	.004	.003	.005	.000	.002
Al	.000	.372	.374	.324	.354	.348
Ti	.002	.003	.008	.108	.005	.002
v	.002	.003	.003	.003	.002	.002
C.E.	.29	.54	.36	.25	.34	.35

Notes: & Average of 3 burns

$$.E. = C + \frac{Mn}{6} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} + \frac{Ni}{40}$$

PHASE MECHANICAL RESULTS TABLE 4

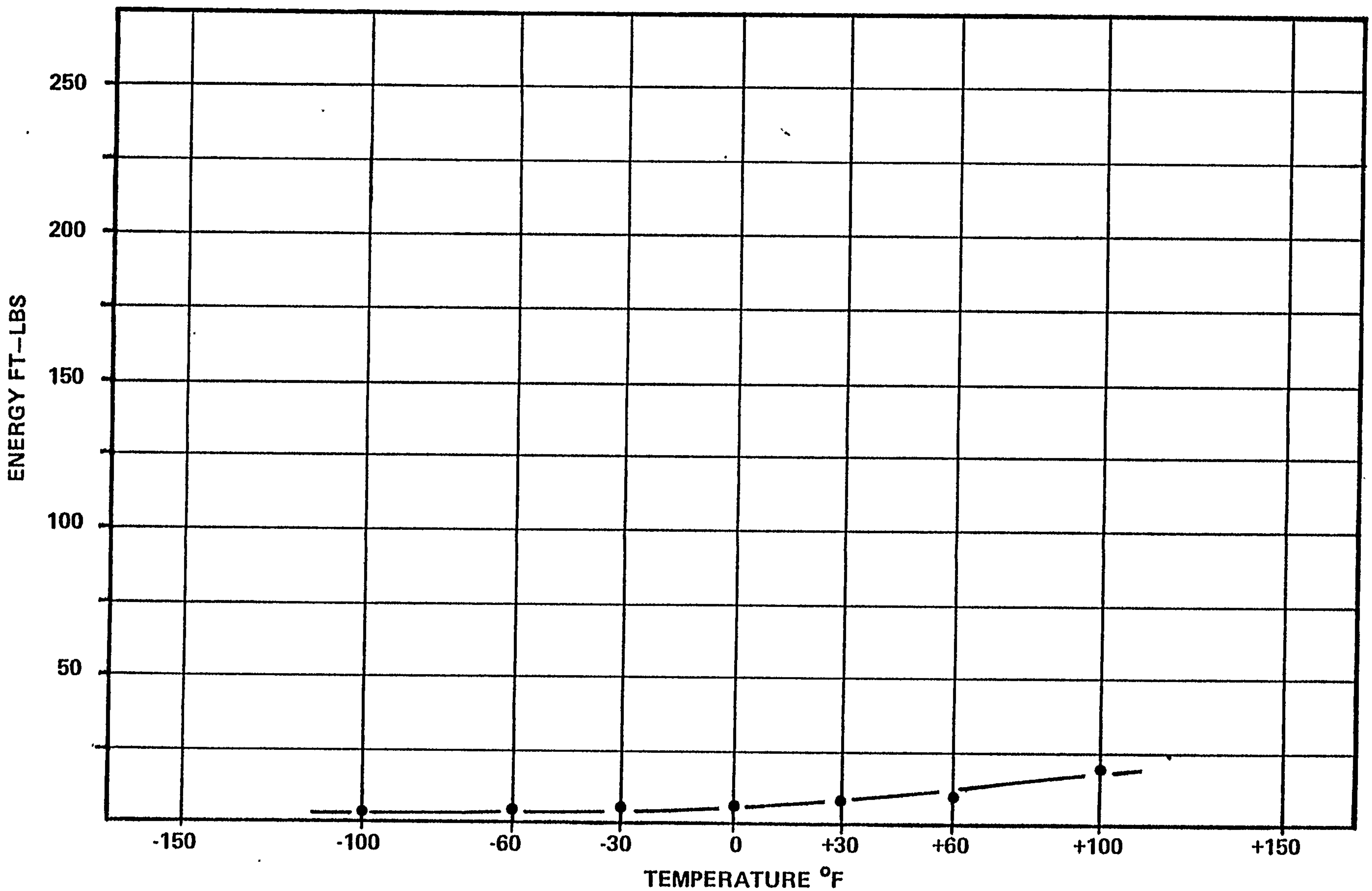
	Airco s-4	Hobart Fab 8	Hobart Fab 8 Ni	Lincoln 302	Lincoln 203M	Lincoln 203 Ni
KJ/IN	34.6	34.1	34.5	34.8	34.1	35.2
Tensile	93,400	90,000	93,300	83,900	72,400	83,400
Yield	71,800	74,000	83,800	76,300	61,300	72,900
Y/T	.77	.82	.90	.91	.85	.87
% Elong.	22	24	23	27	30	28
% R.A.	43	57	57	63	70	69
C.E.	.29	.54	.36	.25	.34	.35

Note: Average of 2 tests

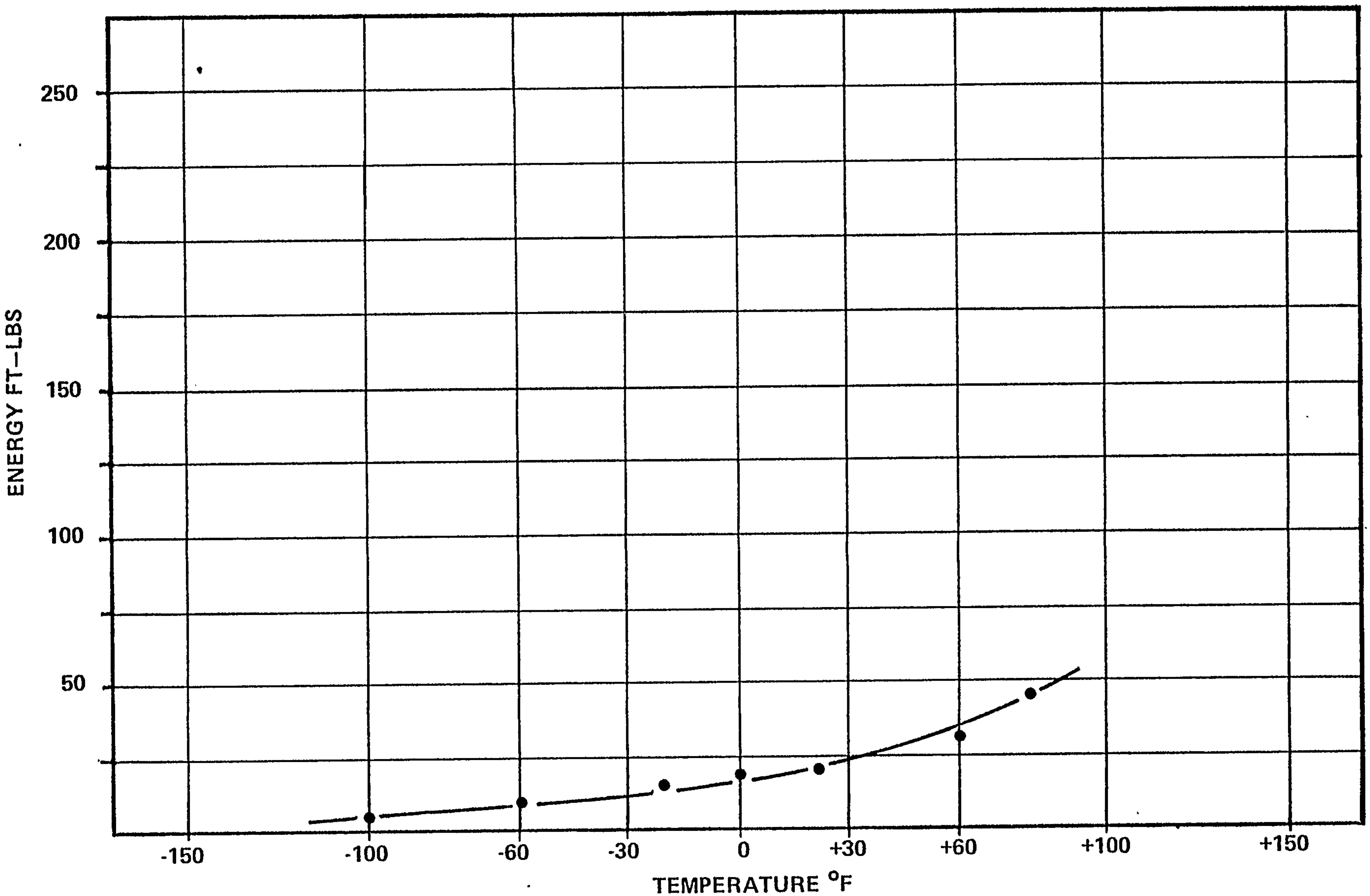
PHASE TOUGHNESS RESULTS TABLE 5

		Airco S-4	Hobart Fab 8	Hobart Fab 8 Ni	Lincoln 302	Lincoln 2 0 3 M	Lincoln 203 Ni
KJ/IN		34.6	34.1	34.5	34.8	34.1	35.2
+100	CV	22.2	53	49.7	53.8	119	107.8
	DT	137	342	545	307	1286	1023
+60	CV	10.7	36.5	41.3	44.7	105.3	96.5
	DT	86	320	437	140	488	559
+30	CV	7.7	22.5	35.7	29.3	95.5	86.7
	DT	75	172	354	64	234	325
O°F	CV	5.2	21.8	25.8	23.3	89	62.7
	DT	40	122	189	53	147	163
-30	CV	4.3	—	18.3	19.3	54.3	47.2
	DT	31	63	139	38	100	100
-60	CV	3.3	10.0	9.5	8.8	31.5	35.0
	DT	34	70	69	40	48	58
-1oo	CV	2.2	3.0	7.5	3.8	7,2	16.3
	DT	30	45	48	40	21	41
NDTT		0°F	-50	-80	-20	-50	-70

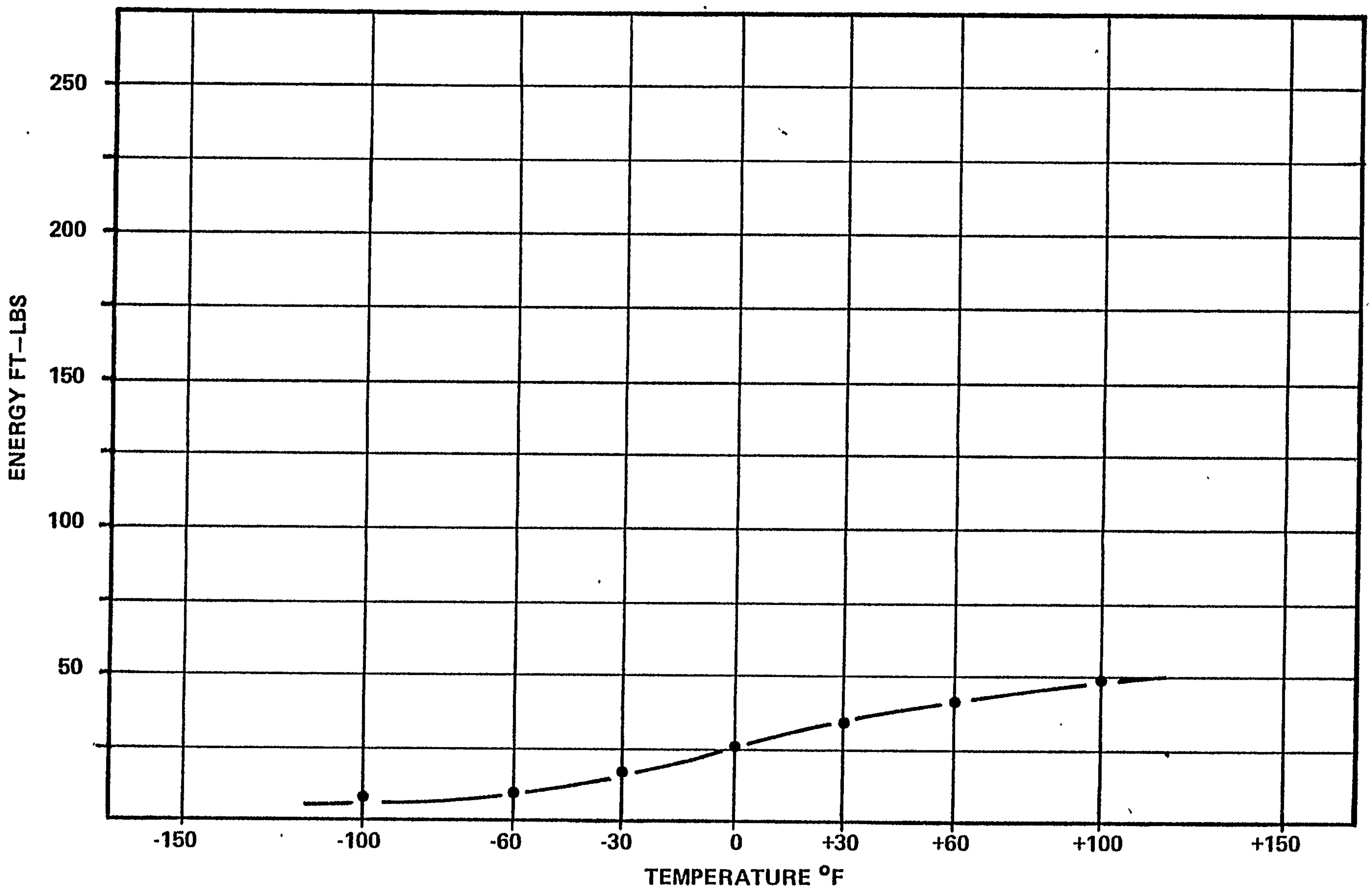
Note: Average of 3 tests



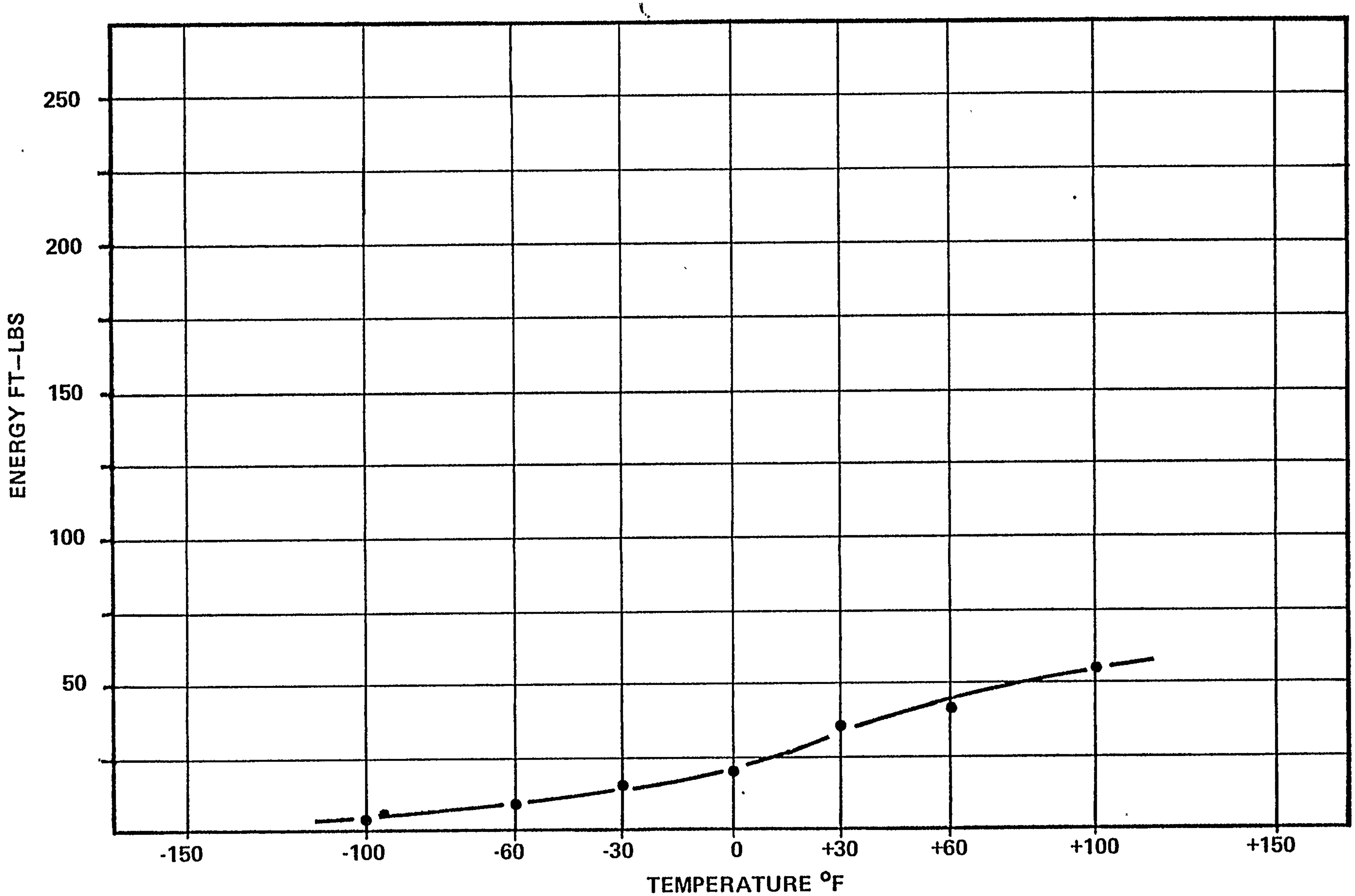
AIRCO SELFSHIELD 4 @ 35 KJ/IN CHARPY V-NOTCH RESULTS FIG. 3



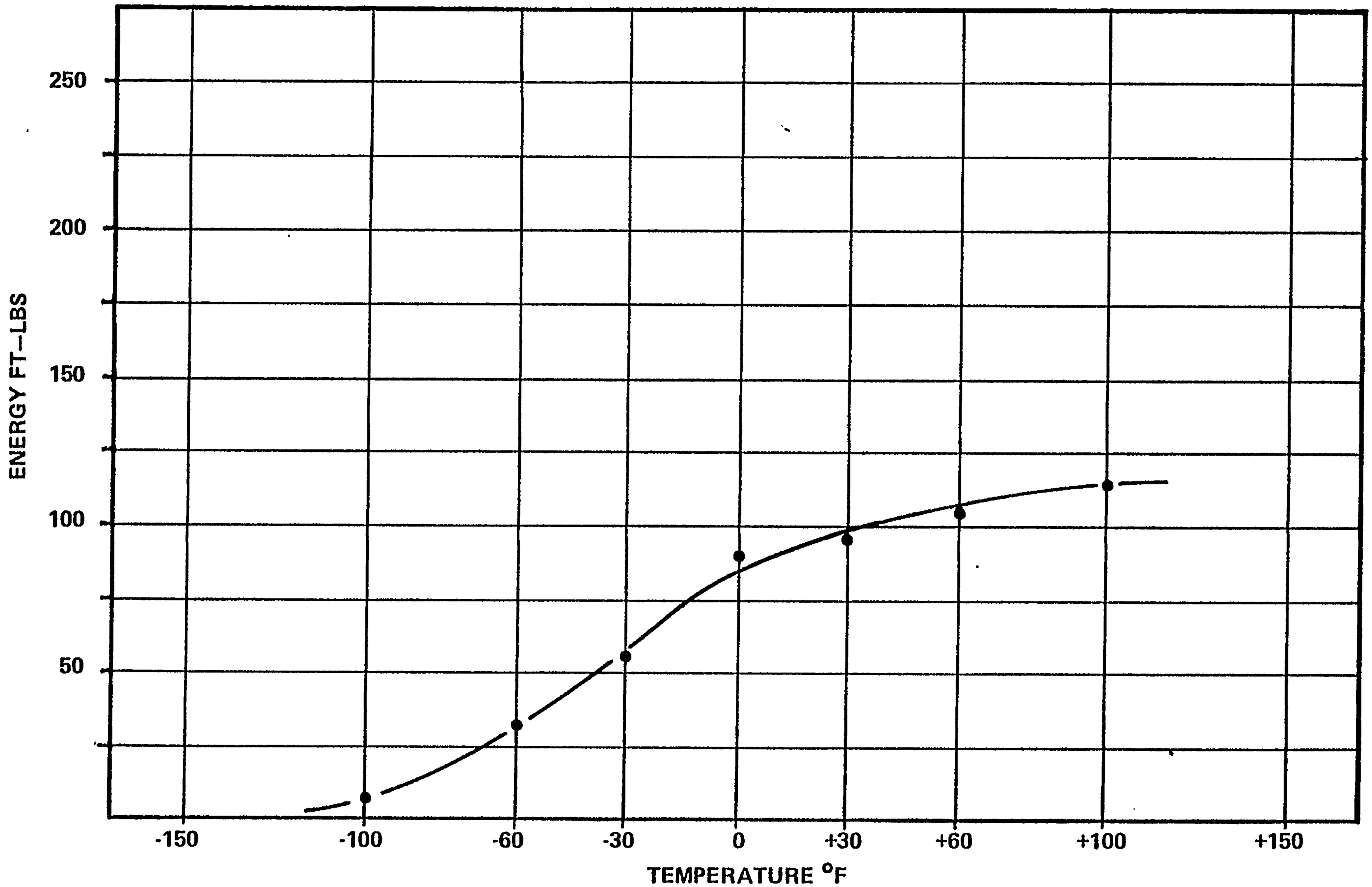
HOBART FABSHIELD 8 @ 35 KJ/IN CHARPY V-NOTCH RESULTS FIG. 4



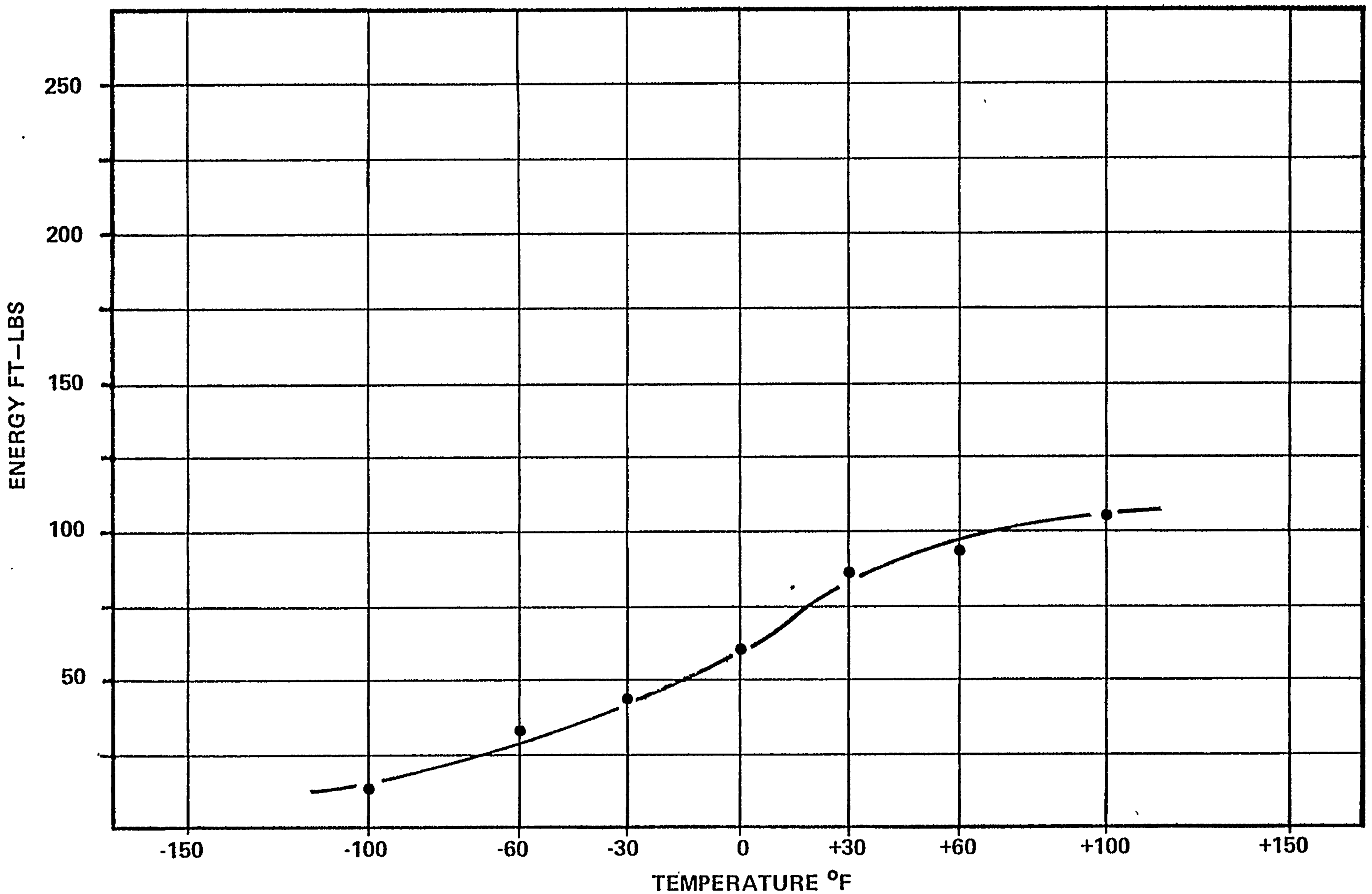
HOBART FABSHIELD 8 Ni @ 35 KJ/IN CHARPY V-NOTCH RESULTS FIG. 5



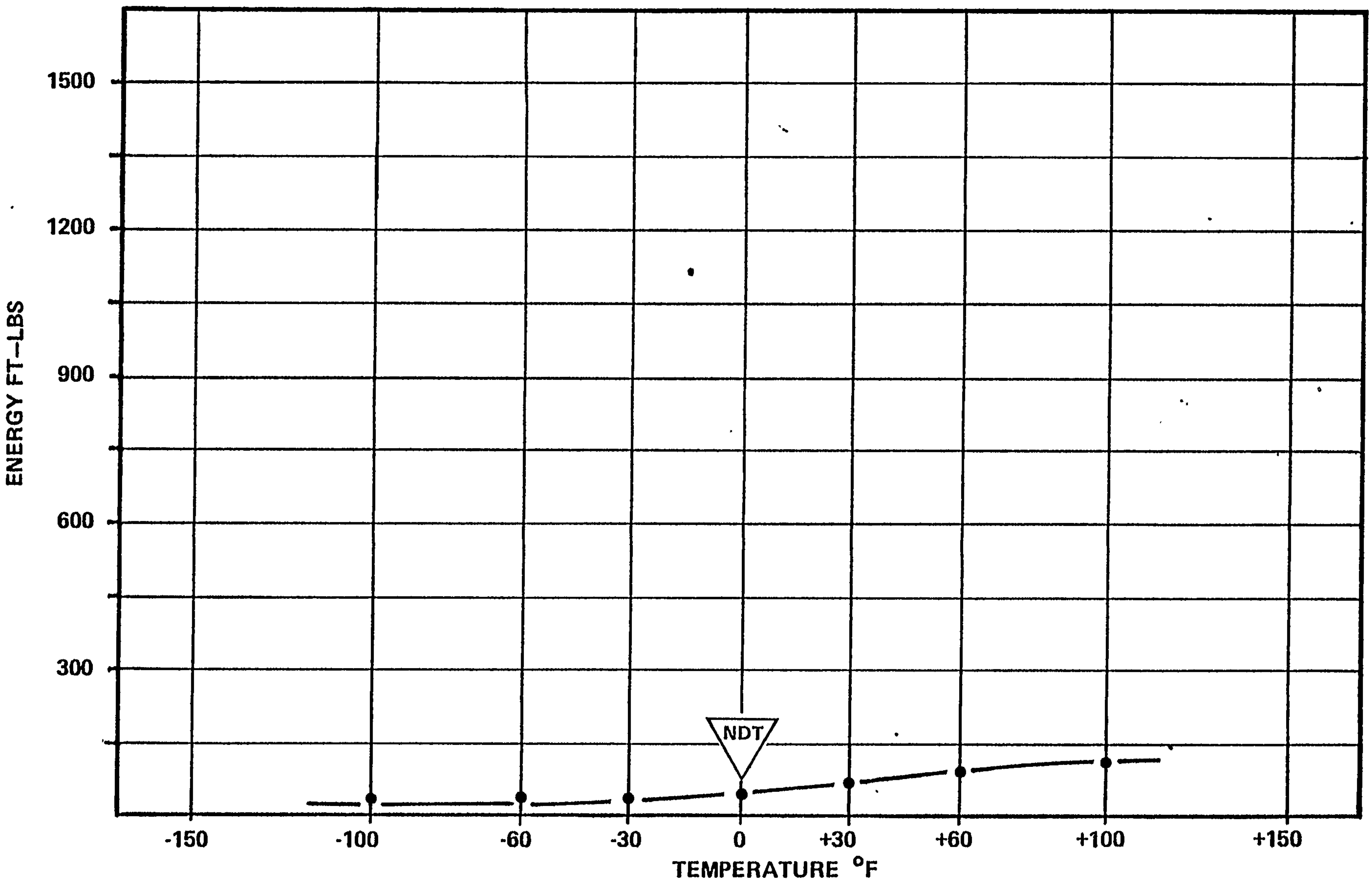
LINCOLN NR302 @ 35 KJ/IN CHARPY V-NOTCH RESULTS FIG. 6



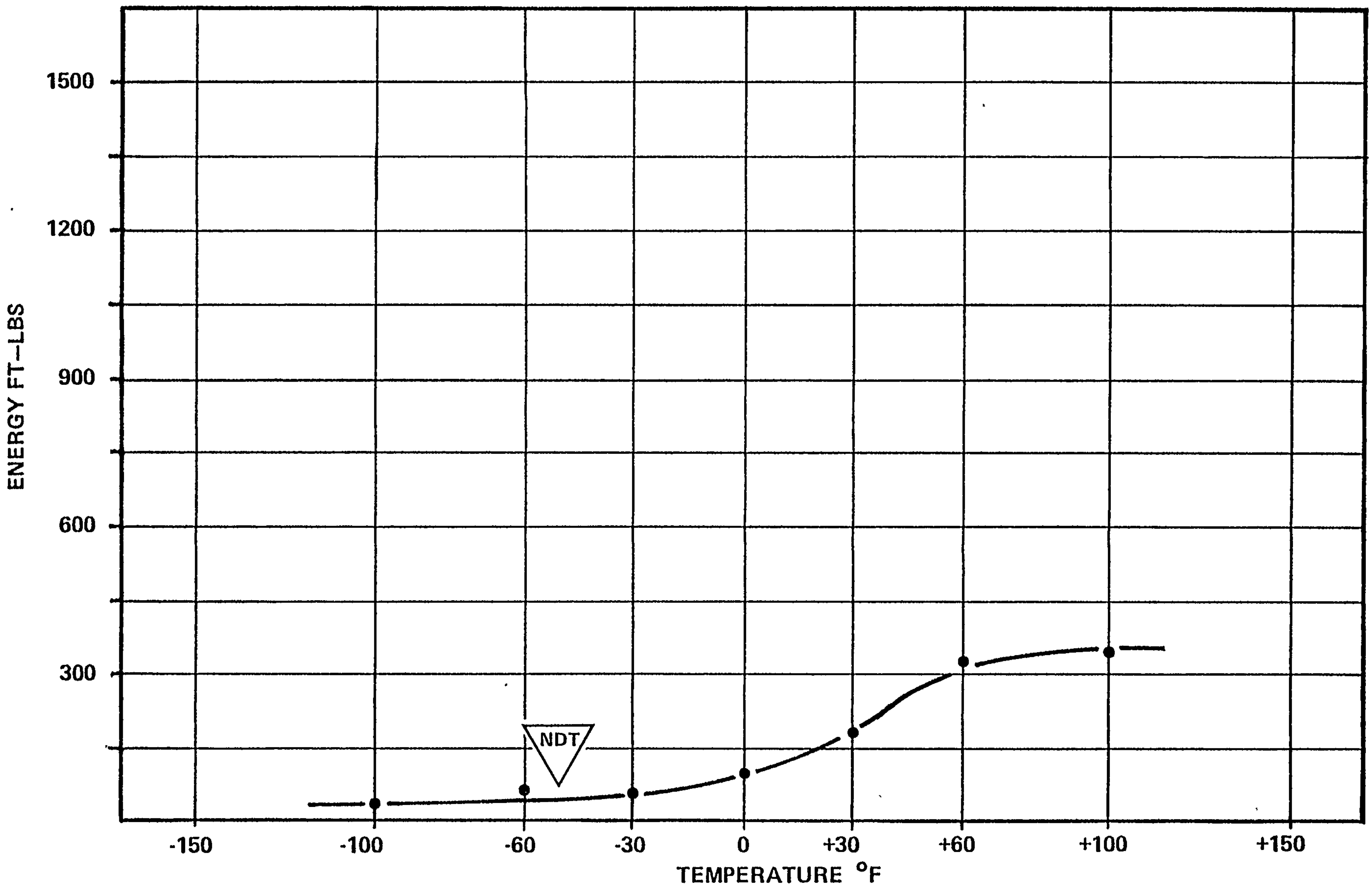
LINCOLN NR203M @ 35 KJ/IN CHARPY V-NOTCH RESULTS FIG. 7



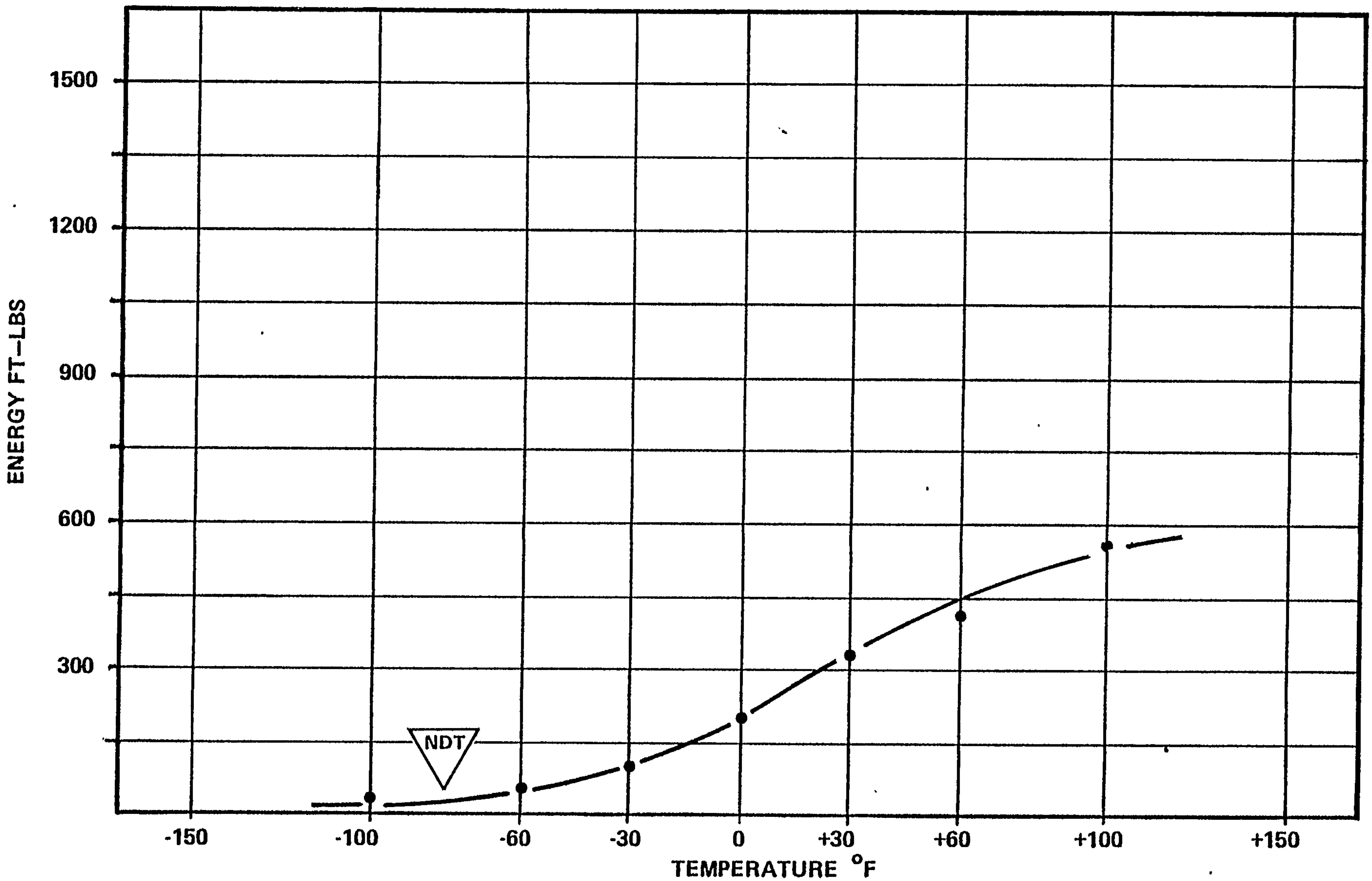
LINCOLN NR203 Ni @ 35 KJ/IN CHARPY V-NOTCH RESULTS FIG. 8



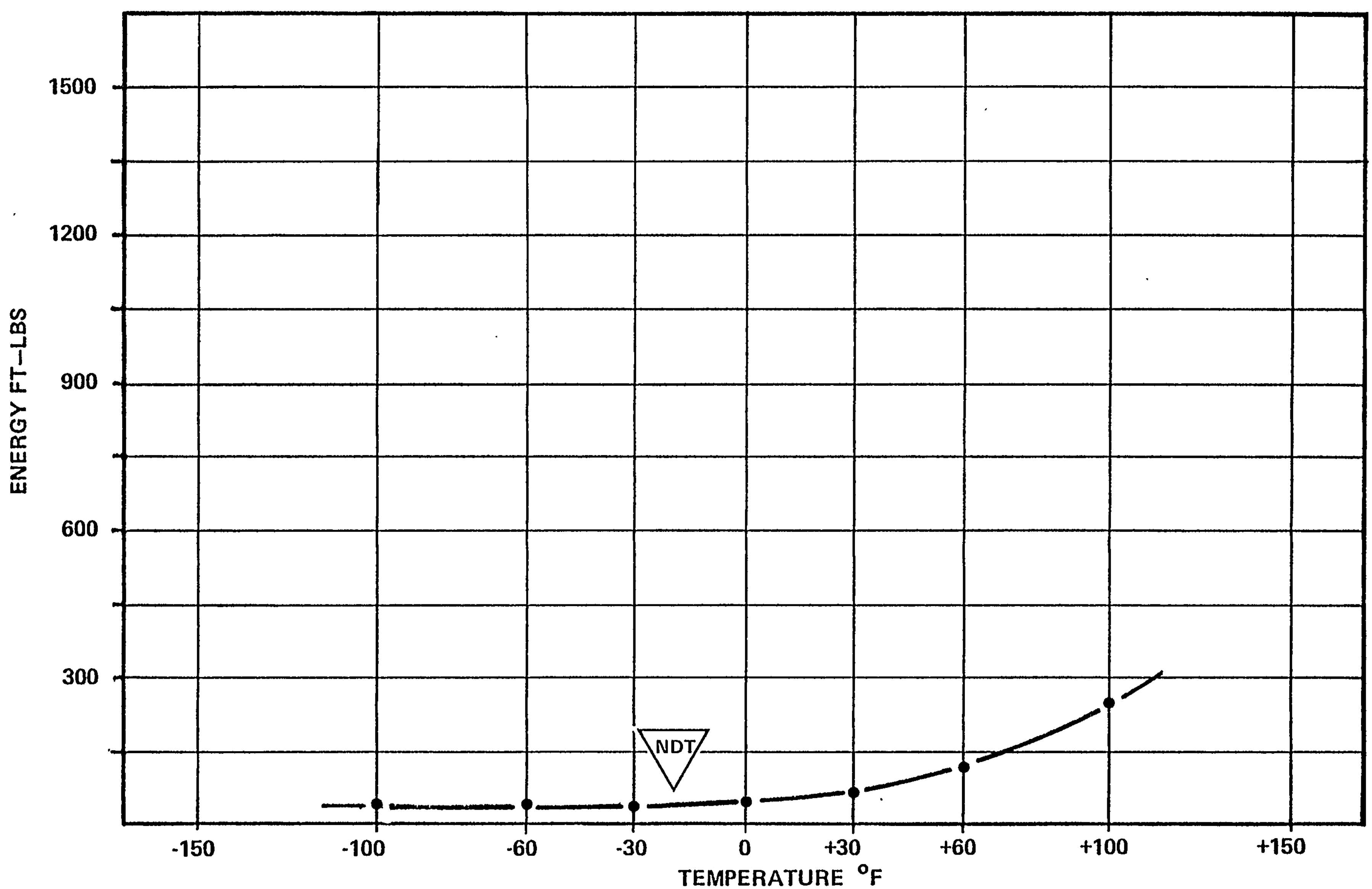
AIRCO SELFSHIELD 4 @ 34 KJ/IN DYNAMIC TEAR RESULTS FIG. 9



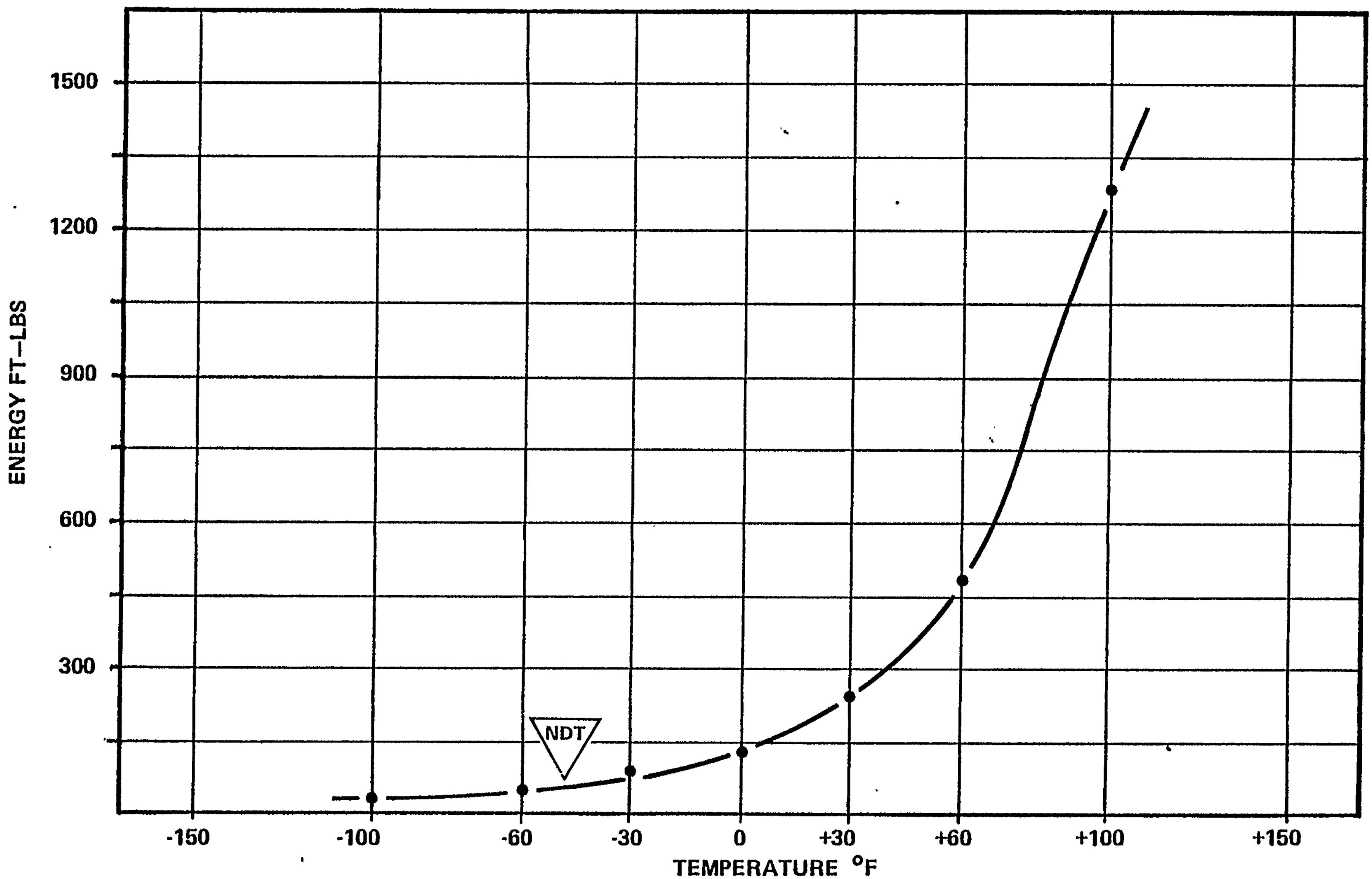
HOBART FABSHIELD 8 @ 34.1 KJ/IN DYNAMIC TEAR RESULTS FIG. 10



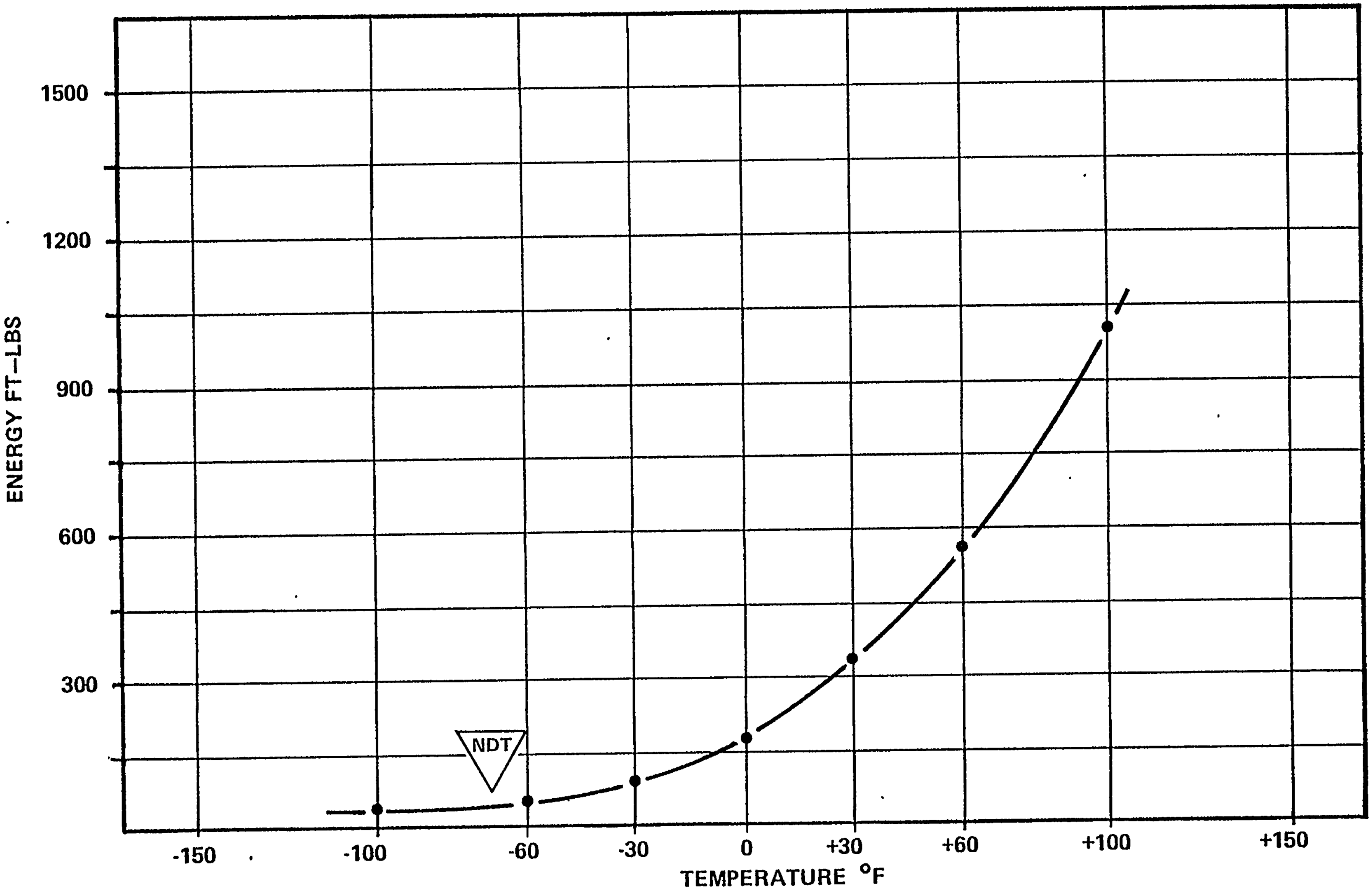
HOBART FABSHIELD 8 Ni @ 34.5 KJ/IN DYNAMIC TEAR RESULTS FIG. 11



LINCOLN NR302 @ 35 KJ/IN DYNAMIC TEAR RESULTS FIG. 12



LINCOLN NR203M @ 35 KJ/IN DYNAMIC TEAR RESULTS FIG. 13



LINCOLN NR203 Ni @ 35 KJ/IN DYNAMIC TEAR RESULTS FIG. 14

APPENDIX II

PHASE II

Tables & Figures

PHASE II PARAMETRIC VARIABLES TABLE 6

	Hobart Fab 8 Ni	Lincoln 302	Lincoln 203M	Lincoln 203 Ni
Diameter	3/32"	3/32"	3/32"	3/32"
Polarity	SP	RP	SP	SP
Stick Out	1"	3/4"	3/4"	3/4,"
KJ/IN	50* 65* 80*	50* 65* 80*	50* 65* 80*	50* 65* 80
Amps	330 330 330	500 500 500	300 300 300	300s 300 300
volts	22.5 22.5 23	28 28 28	20 20 20	21 21 21
Travel 1PM	8.9 6.9 5.5	16.8 12.8 10.5	7.5 5.5 4.5	7.5 5.8 4.7
No. of Passes	13 10 7	11 8 7	12/13 10 6	12/13 8/10 6

*Denotes common wire eat

PHASE II CHEMICAL RESULTS TABLE 7

Wire	Hobart Fab 8 Ni	Lincoln 302	Lincoln 203M	Lincoln 203 Ni
KJ/IN	65	65	65	65
c	.101	.090	.075	.091
Mn	1.219	.917	1.528	1.269
P	.005	.004	.002	.003
Si	.184	.280	.209	.264
Ni	2.150	.032	.012	.818
Cr	.015	.018	.019	.022
Mo	.033	.044	.043	.032
Cu	.020	.013	.009	.008
S	.003	.005	.000	.001
Al	.372	.317	.369	.372
Ti	.008	.115	.005	.002
v	.003	.003	.002	.002
C.E.	.37	.25	.34	.33

Notes: (1) Average of 3 tests

(2) $C.E. = C + \frac{Mn}{6} + \frac{Cr}{5} + \frac{Mo}{7} + \frac{V}{14} + \frac{Ni}{40}$

PHASE II MECHANICAL RESULTS TABLE 8

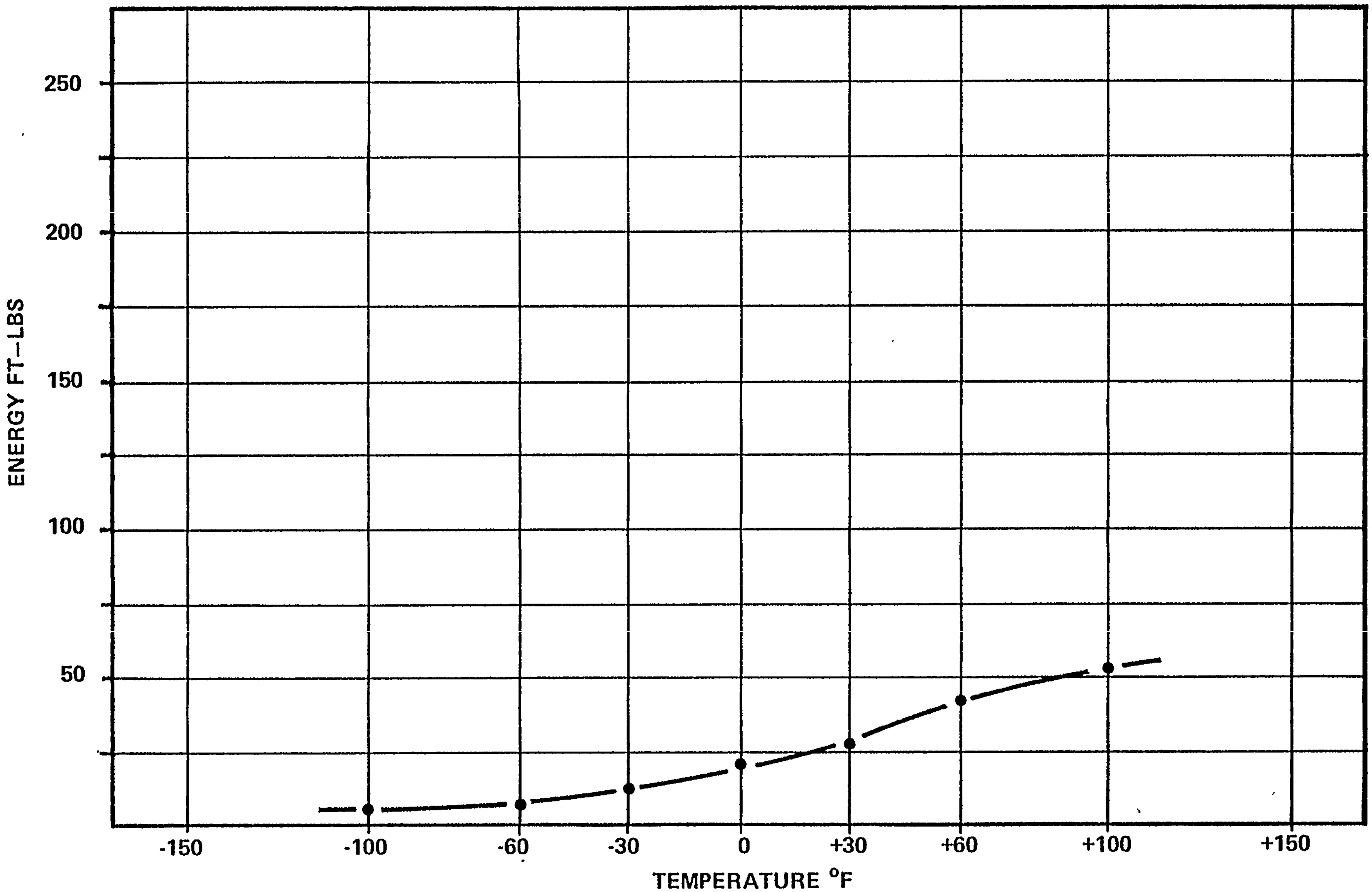
	Hobart Fab 8 Ni			Lincoln 302			Lincoln 203M			Lincoln 203 Ni		
KJ/IN	50*	65*	80*	50*	65*	80*	50*	65*	80*	50*	65*	80
Tensile	88,700	94,300	86,300	82,700	74,100	72,200	73,900	68,300	69,700	77,400	73,900	78,400
Yield	73,700	77,600	63,000	68,900	61,100	58,800	61,700	58,100	54,100	63,700	58,700	61,700
Y/T	.83	.82	.73	.83	.82	.81	.83	.85	.78	.82	.79	.79
% Elong.	27	23	27	23	30	34	32	33	34	32	35	34
% R.A.	63	–	61	63	67	68	75	76	77	72	73	69
C.E.		.37			.25			.34			.33	

Notes: (1) Average of 2 tests
(2) * denotes common wire heat

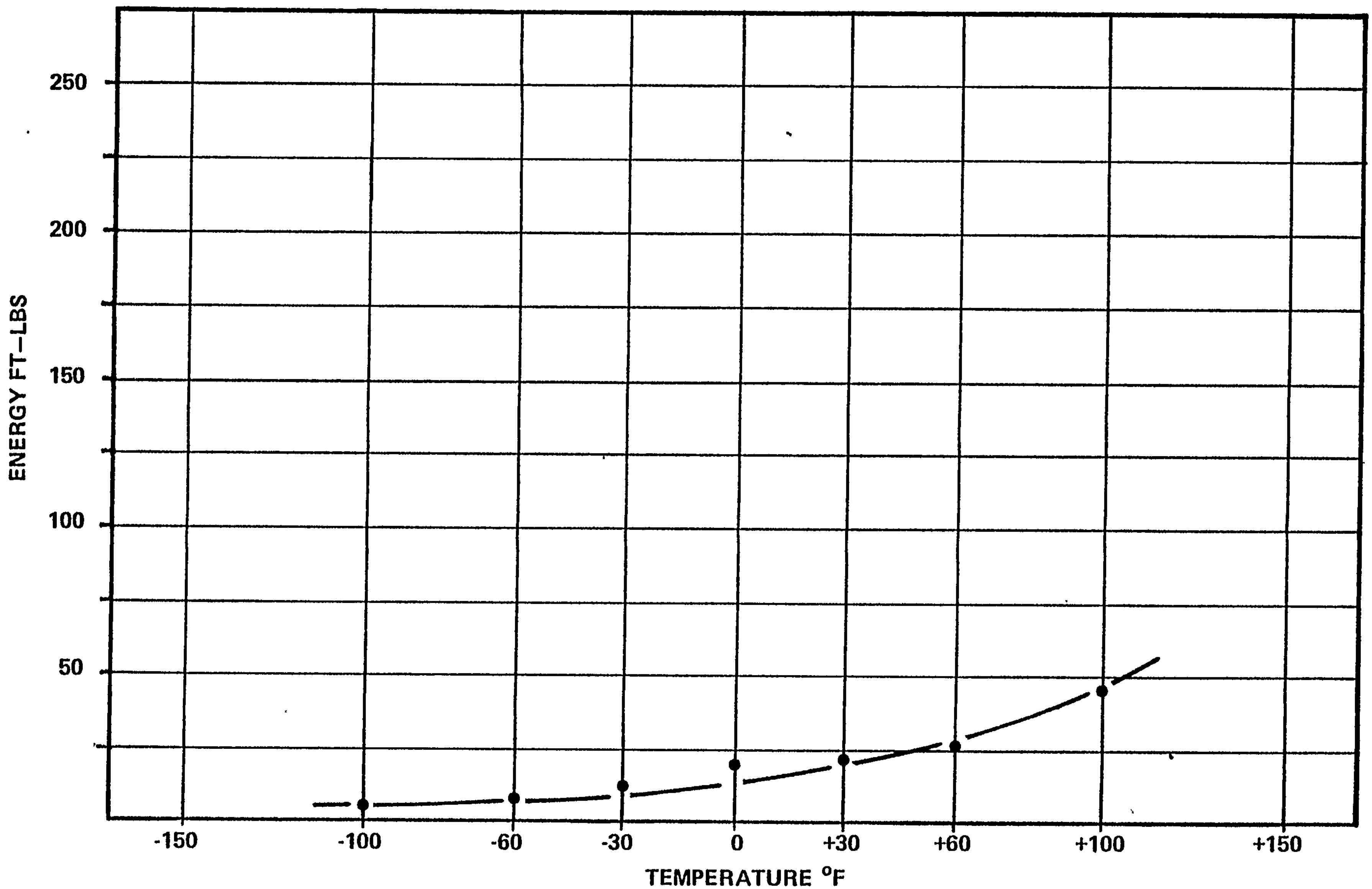
PHASE II TOUGHNESS RESULTS TABLE 9

		Hobart 8 Ni			Lincoln 302			Lincoln 203M			Lincoln 203 Ni		
KJ/IN		50*	65*	80*	50*	65*	80*	50*	65*	80*	50*	65*	80
+100	CV	47.8	45.5	41.0	46.5	74.0	79.0	157.0	216.3	200.7	112.3	123.0	90.8
	DT	658	662	513	206	570	426	1470	1357	1362	1098	921	960
+60	CV	41.3	26.7	28.1	23.3	52.2	61.7	119.3	188.7	113.3	88.7	113.0	60.0
	DT	416	630	253	138	347	312	434	1075	618	932	524	353
+30	CV	26.7	21.5	19.8	20.3	43.0	55.3	108.0	161.0	103.0	78.0	90.3	44.7
	DT	191	332	180	80	189	145	232	682	227	578	413	270
O°F	CV	20.3	19.7	13.0	14.5	36.0	43.5	75.5	145.7	71.3	52.7	82.3	33.3
	DT	120	200	101	52	132	113	106	152	117	499	252	129
-30	CV	12.7	12.0	10.0	7.3	24.8	35.0	62.3	98.3	44,3	28.0	48.0	26.7
	DT	66	109	59	48	83	34	66	97	71	119	63	70
-60	CV	6.5	8.5	12.2	5.2	13.3	28.8	20.3	66.7	18.8	20.7	43.7	18.0
	DT	46	47	43	39	59	41	48	90	46	84	65	36
-100	CV	5.8	4.2	4.2	4.0	5.3	7.2	9.7	35.8	5.8	8.7	35.7	7.8
	DT	45	44	41	32	32	24	45	39	42	31	39	30
NDTT		-50	-40	-60	0	-60	-50	-50	-50	-90	-70	-60	-60

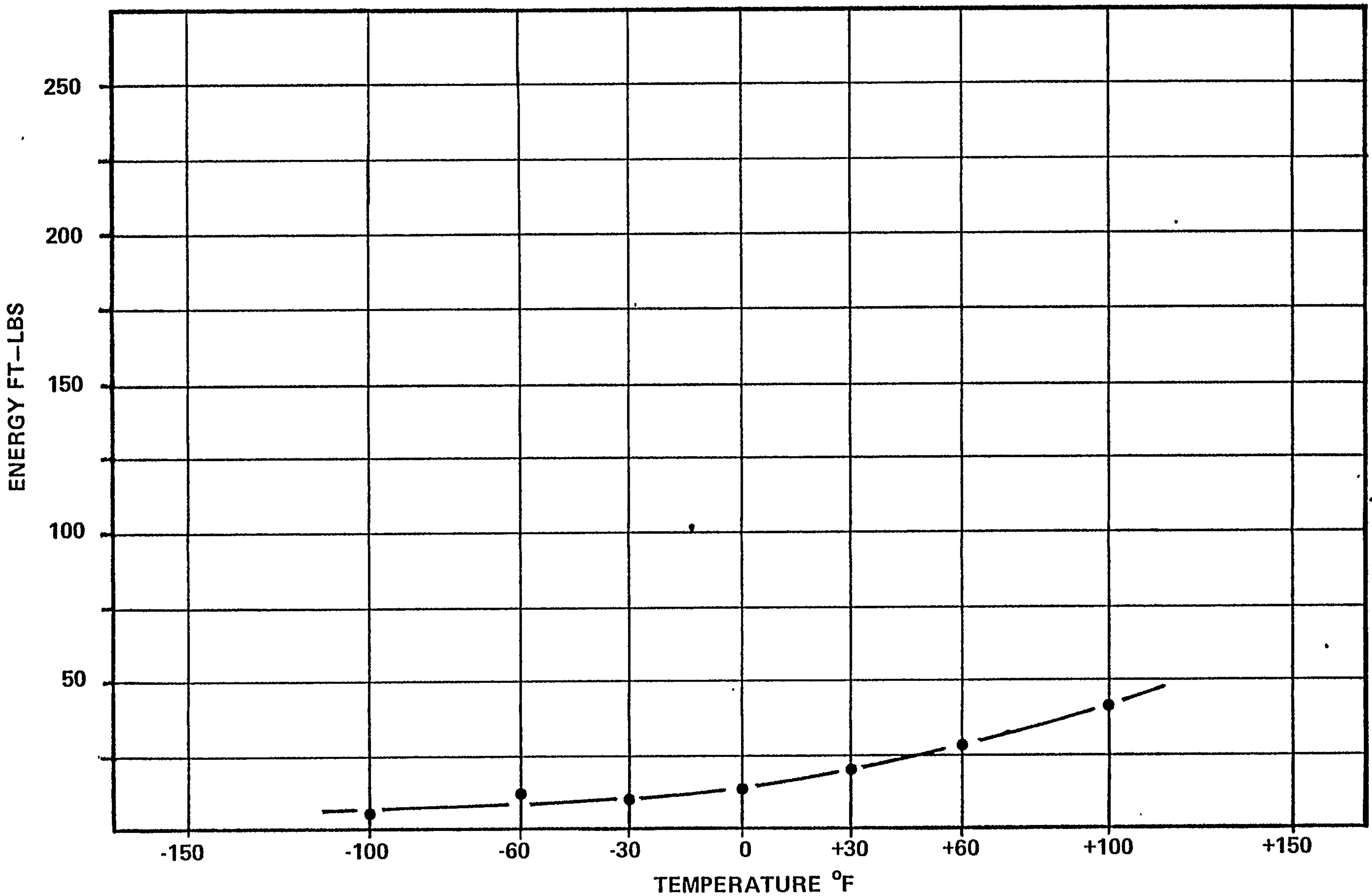
Note: Average of 3 tests
*Denotes common wire heat



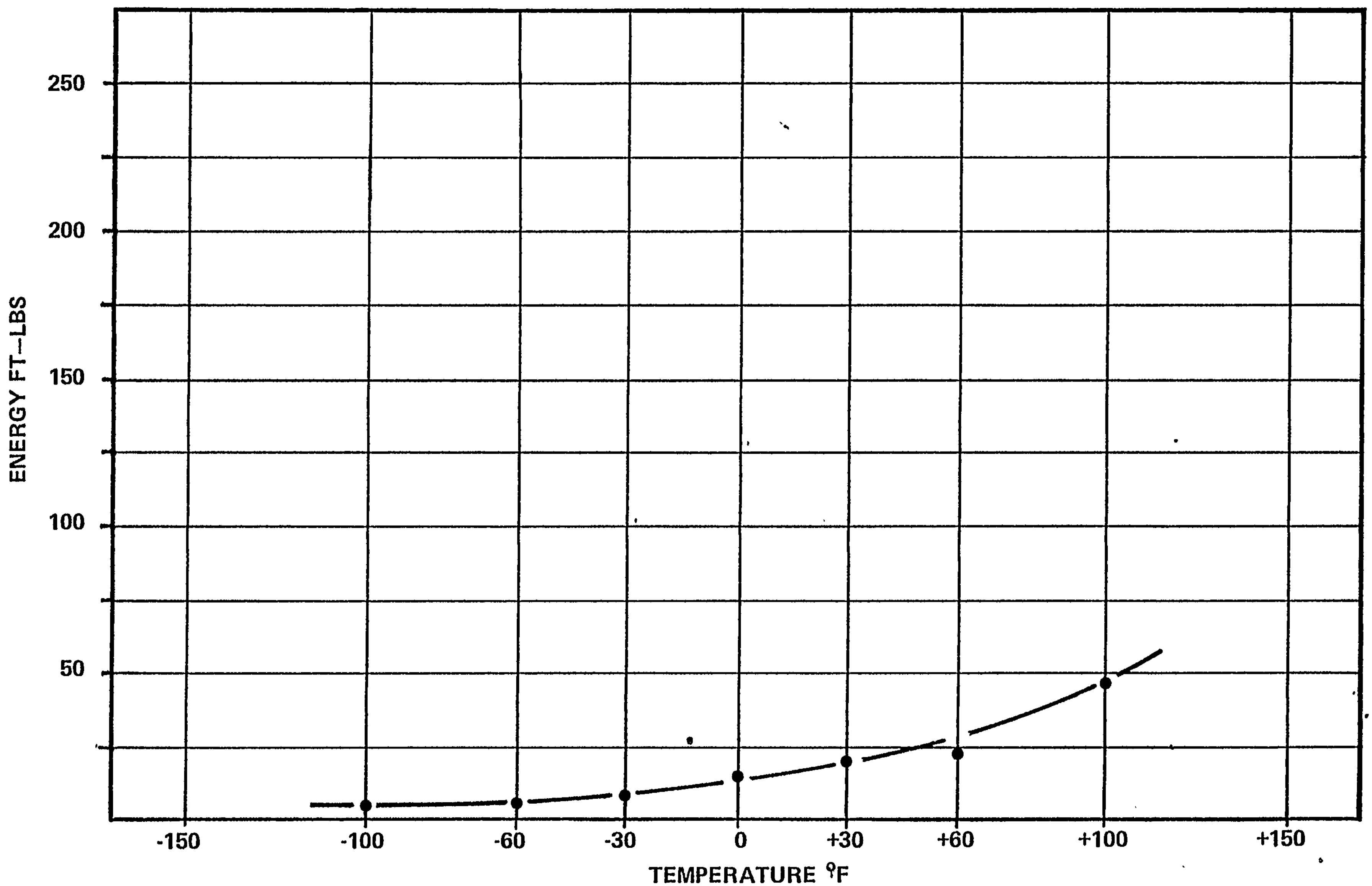
HOBART FABSHIELD 8 Ni @ 50 KJ/IN	CHARPY V-NOTCH RESULTS	FIG. 15



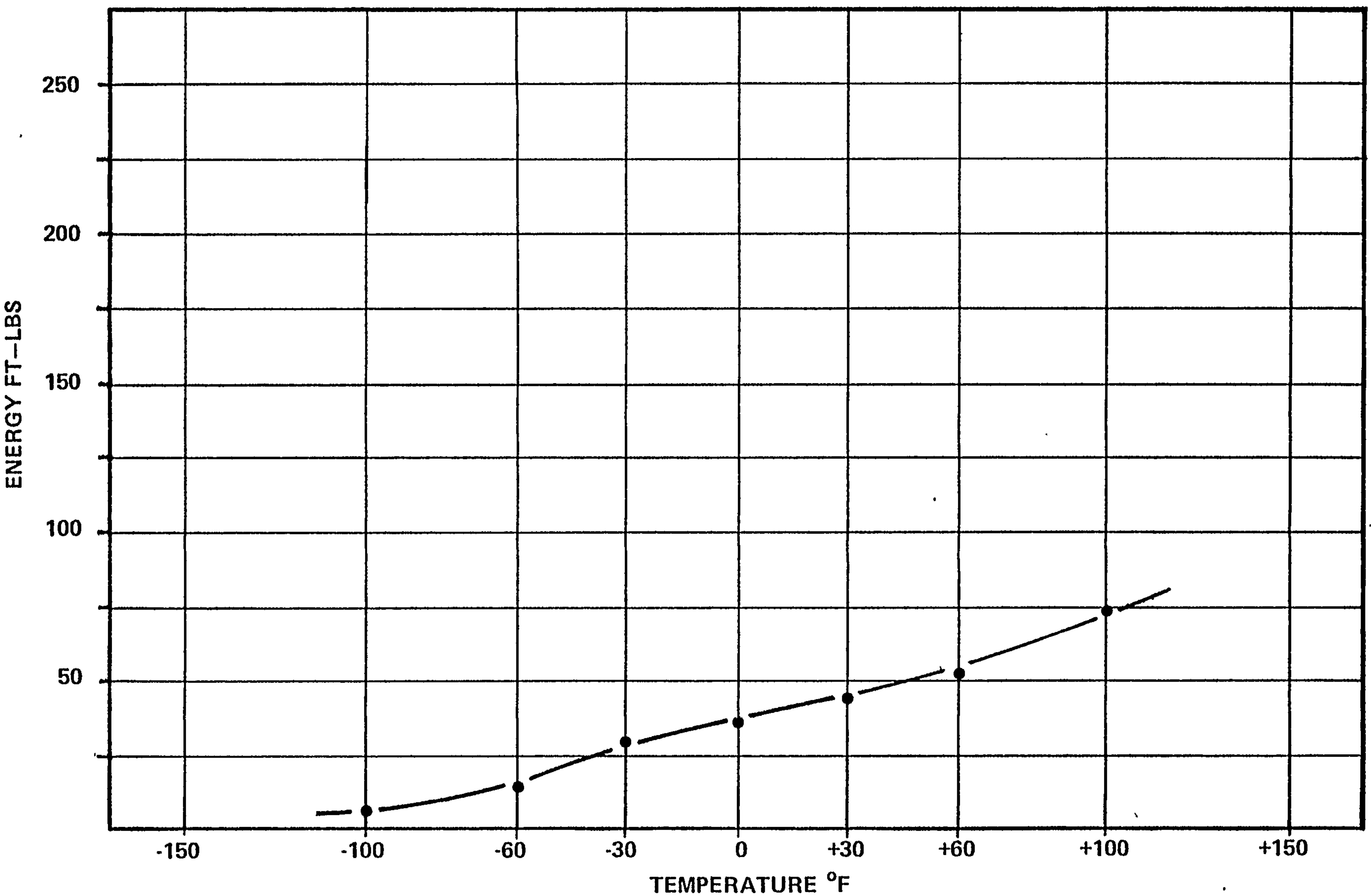
HOBART FABSHIELD 8 Ni @ 65 KJ/IN CHARPY V-NOTCH RESULTS FIG. 16



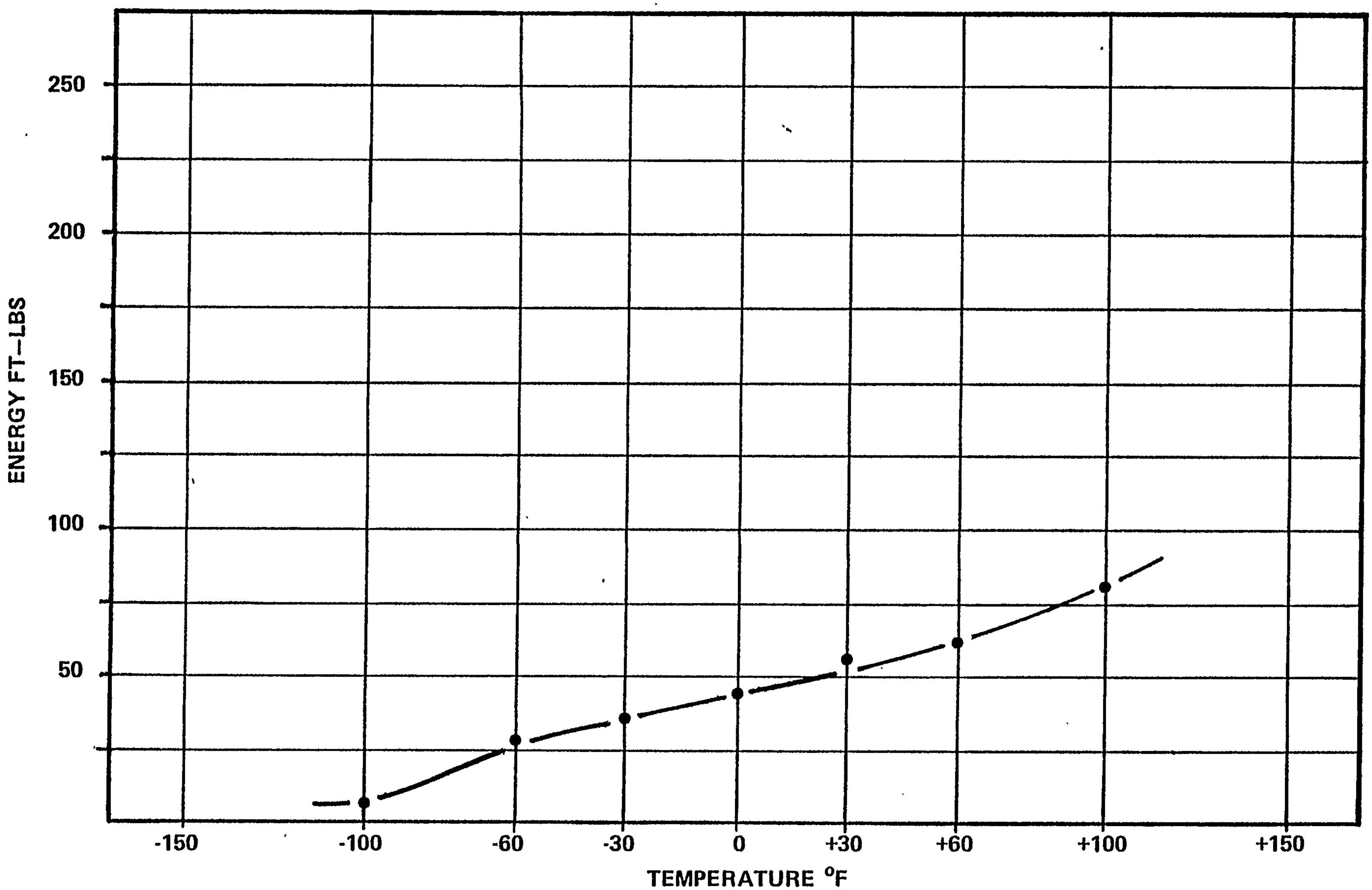
HOBART FABSHIELD 8 Ni @ 80 KJ/IN   CHARPY V-NOTCH RESULTS   FIG. 17



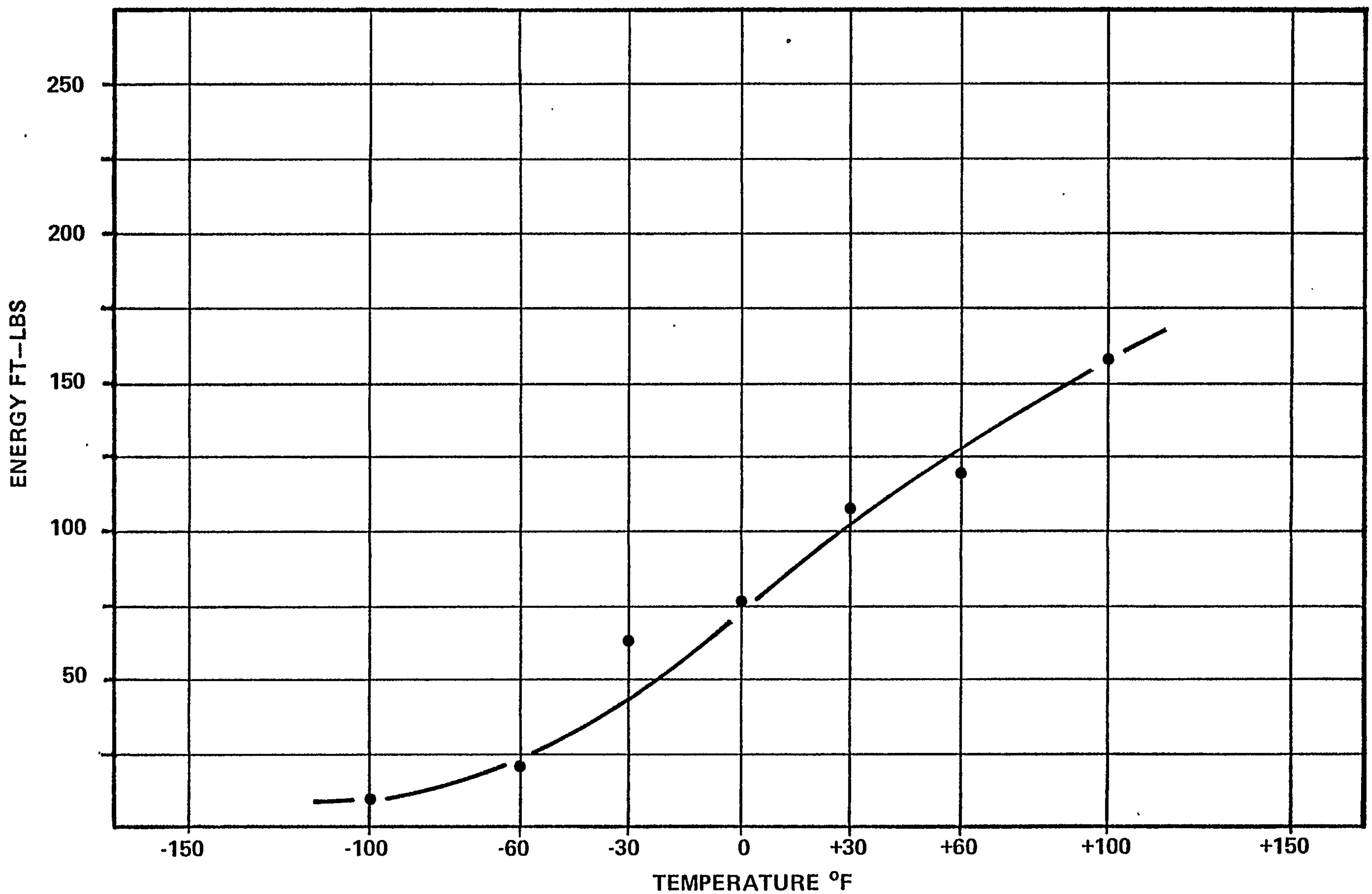
LINCOLN NR302 @ 50 KJ/IN CHARPY V-NOTCH RESULTS FIG. 18



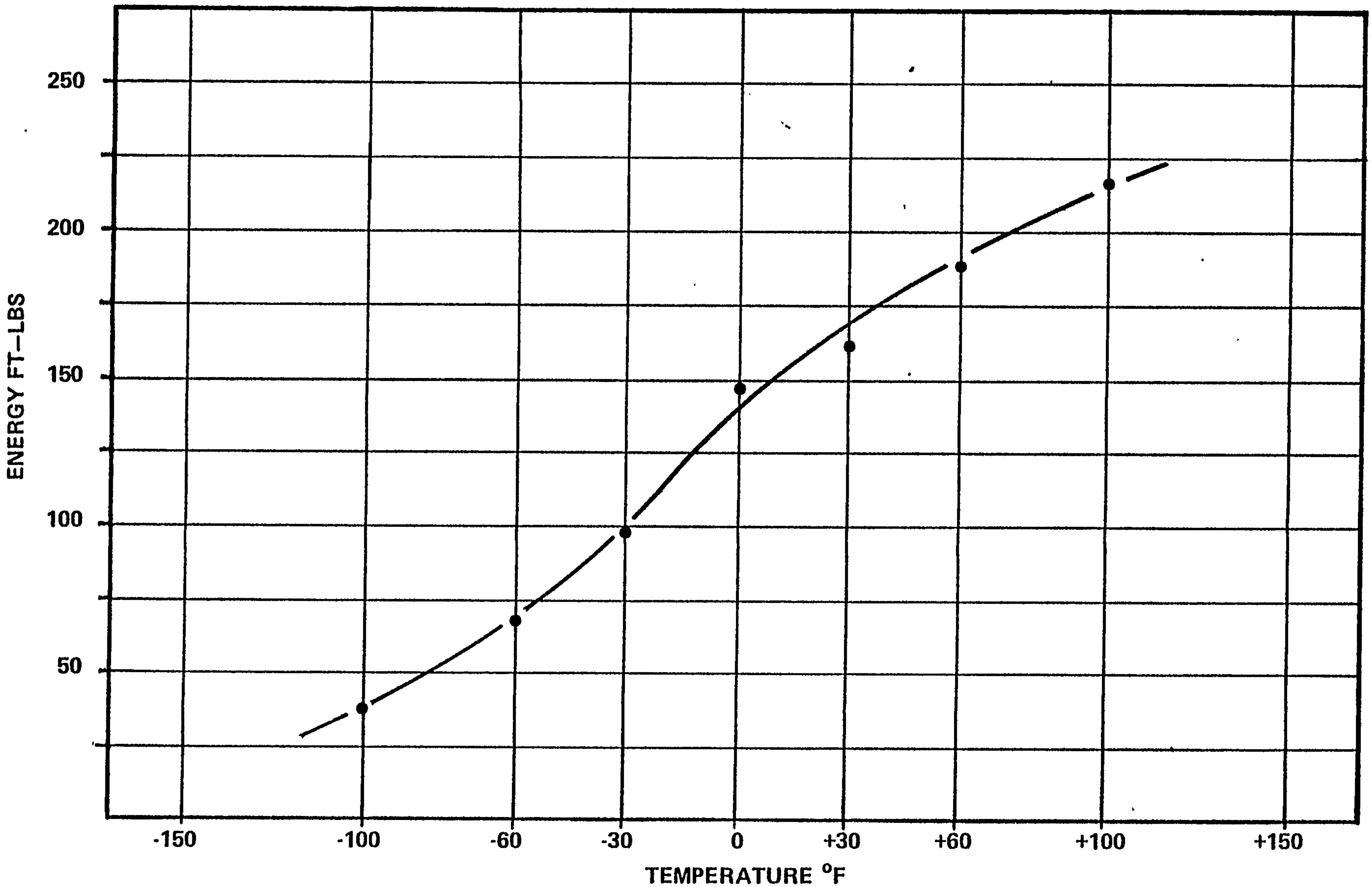
LINCOLN NR302 @ 65 KJ/IN CHARPY V-NOTCH RESULTS FIG. 19



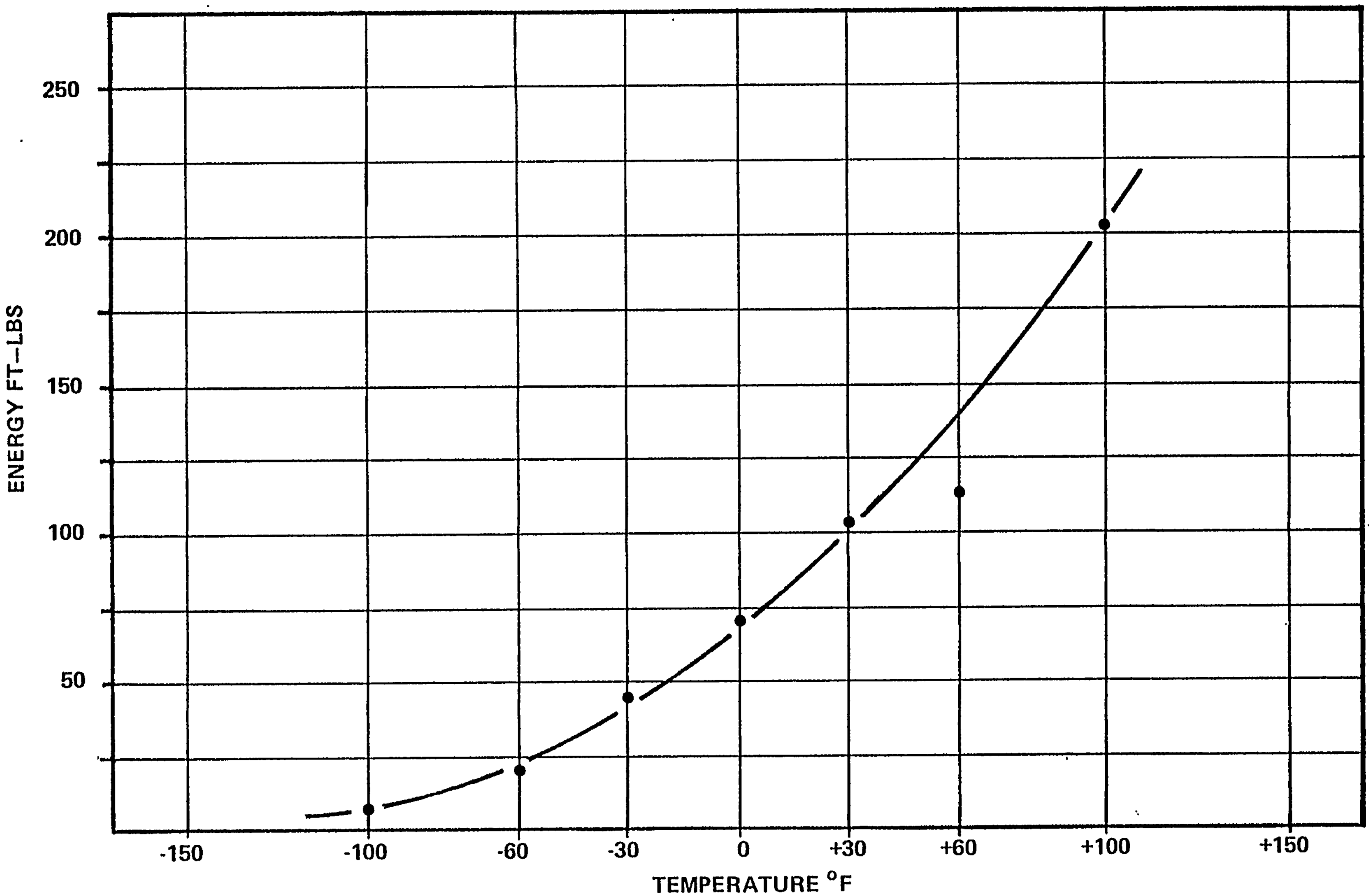
LINCOLN NR302 @ 80 KJ/IN CHARPY V-NOTCH RESULTS FIG. 20



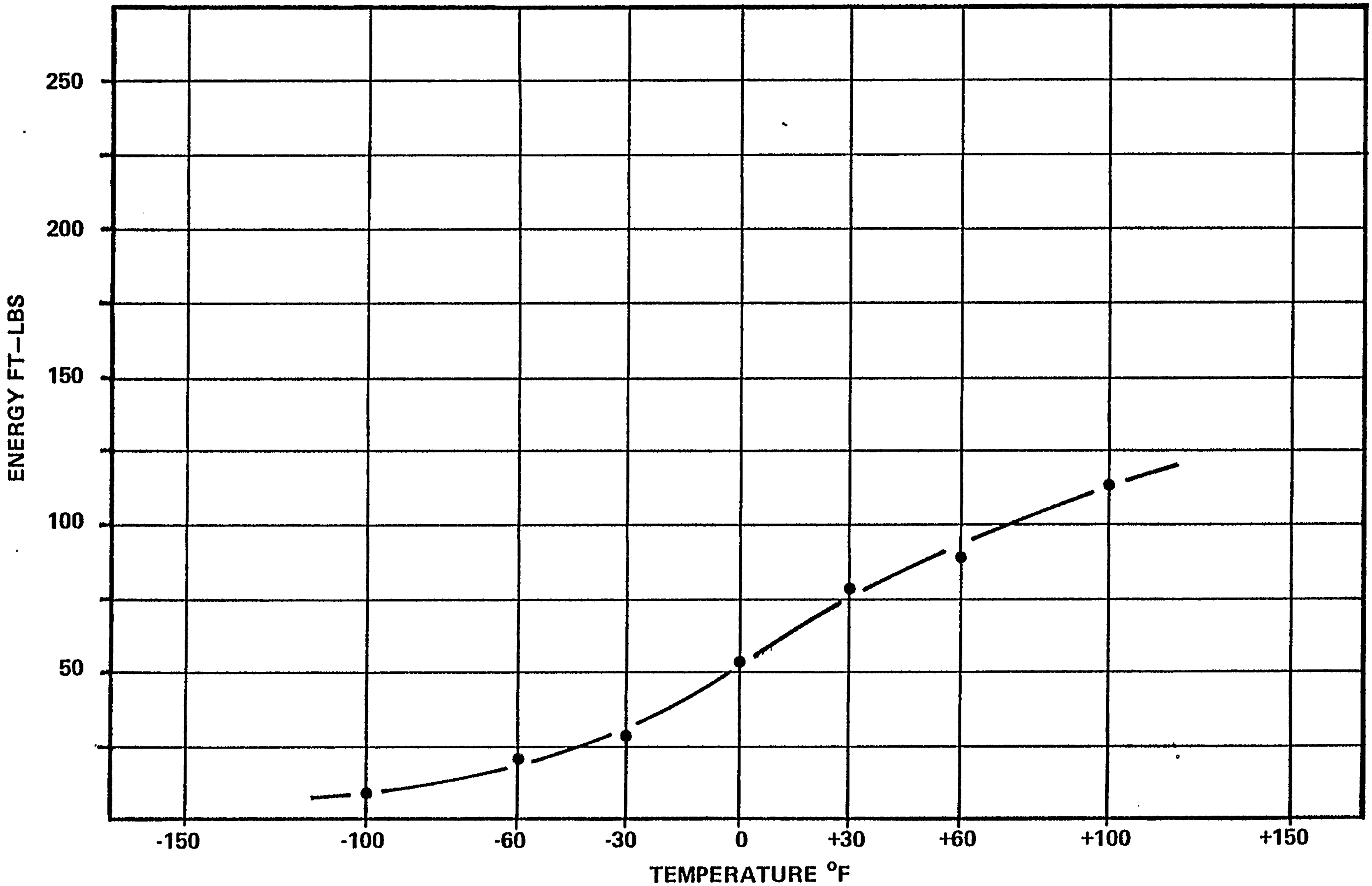
LINCOLN NR203M @ 50 KJ/IN CHARPY V-NOTCH RESULTS FIG. 21



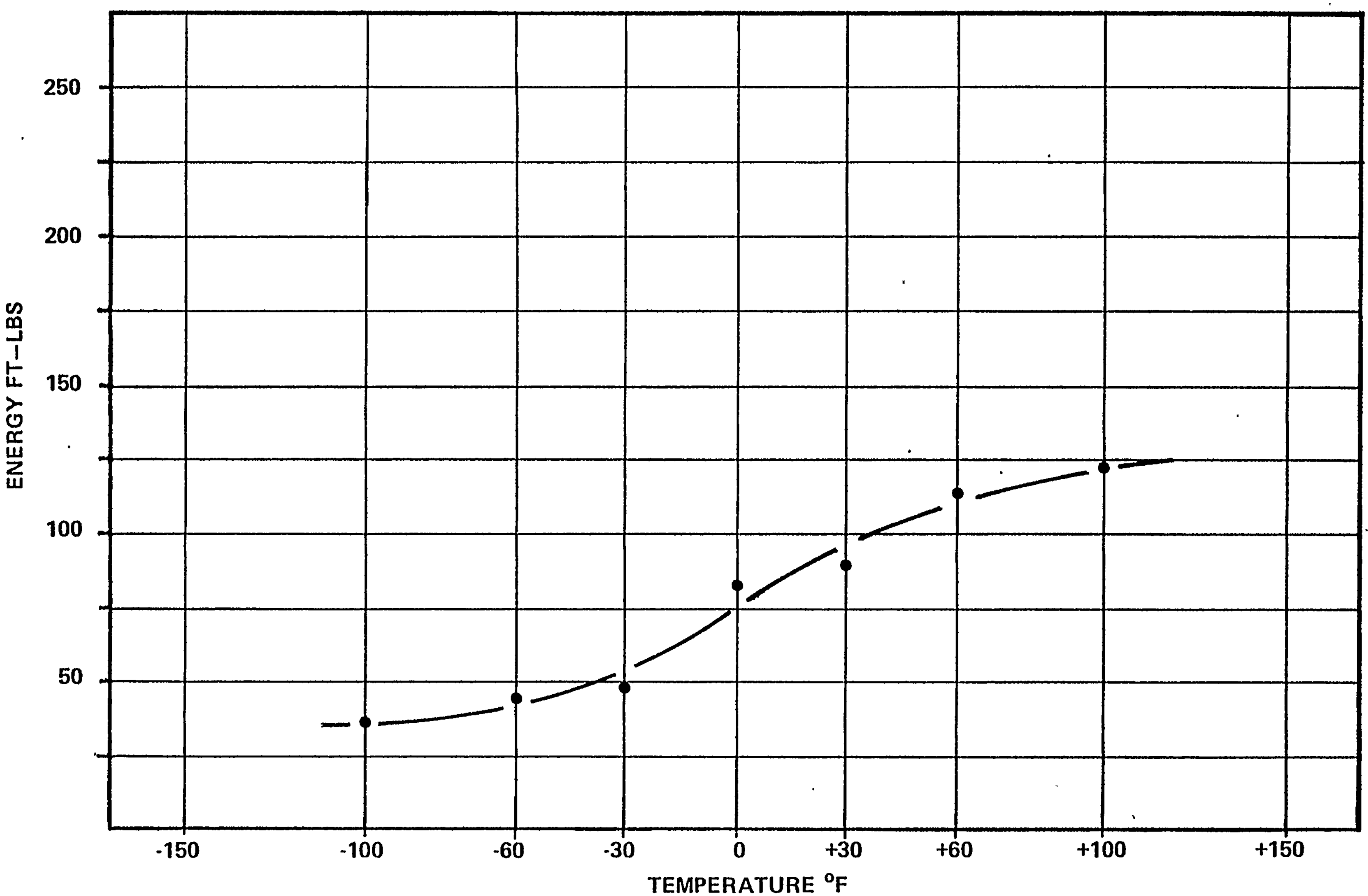
LINCOLN NR203M @ 65 KJ/IN CHARPY V-NOTCH RESULTS FIG. 22



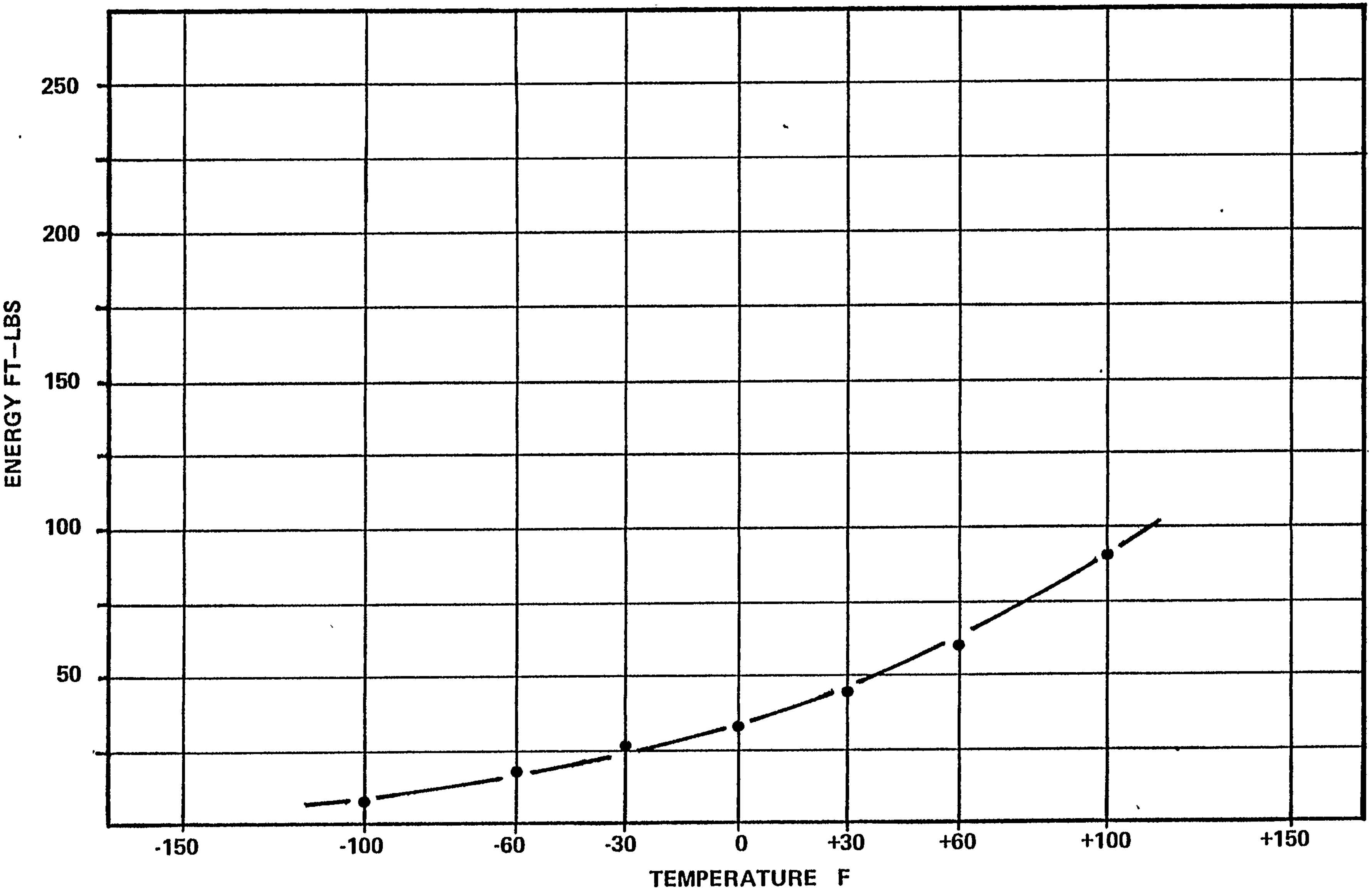
LINCOLN NR203M @ 80 KJ/IN CHARPY V-NOTCH RESULTS FIG. 23



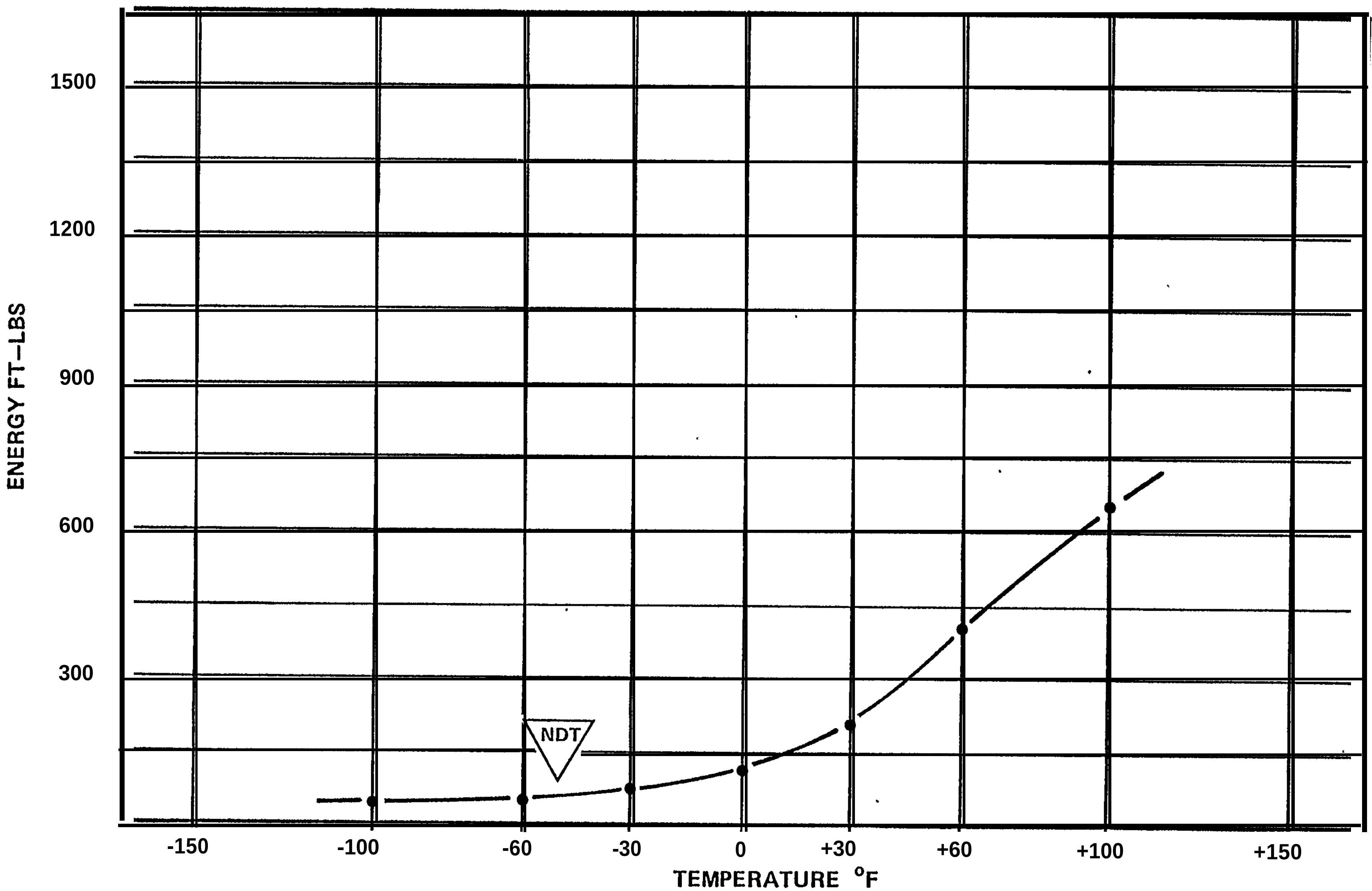
LINCOLN NR203 Ni @ 50 KJ/IN   CHARPY V-NOTCH RESULTS   FIG. 24



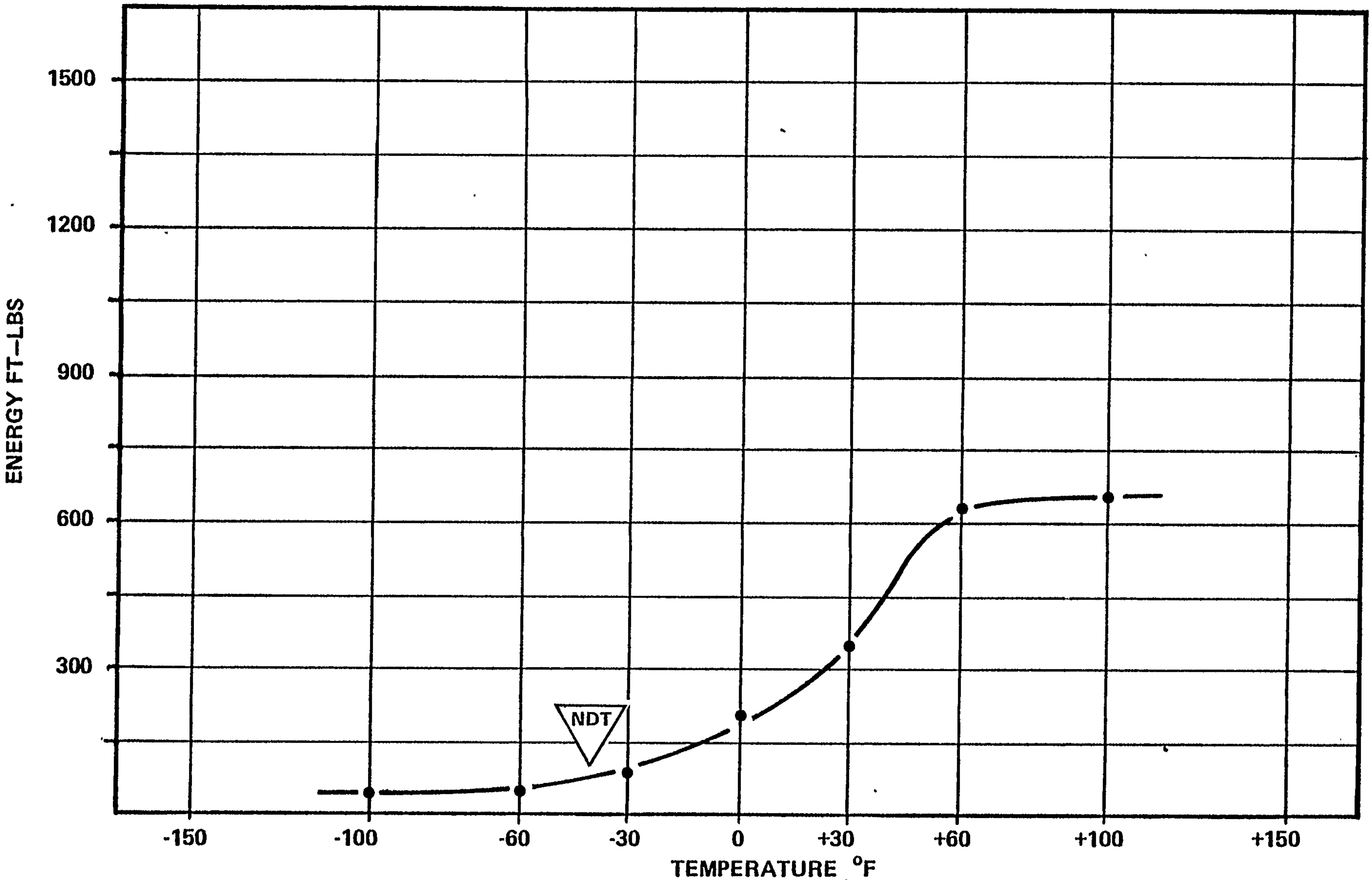
LINCOLN NR203 Ni @ 65 KJ/IN CHARPY V-NOTCH RESULTS FIG. 25



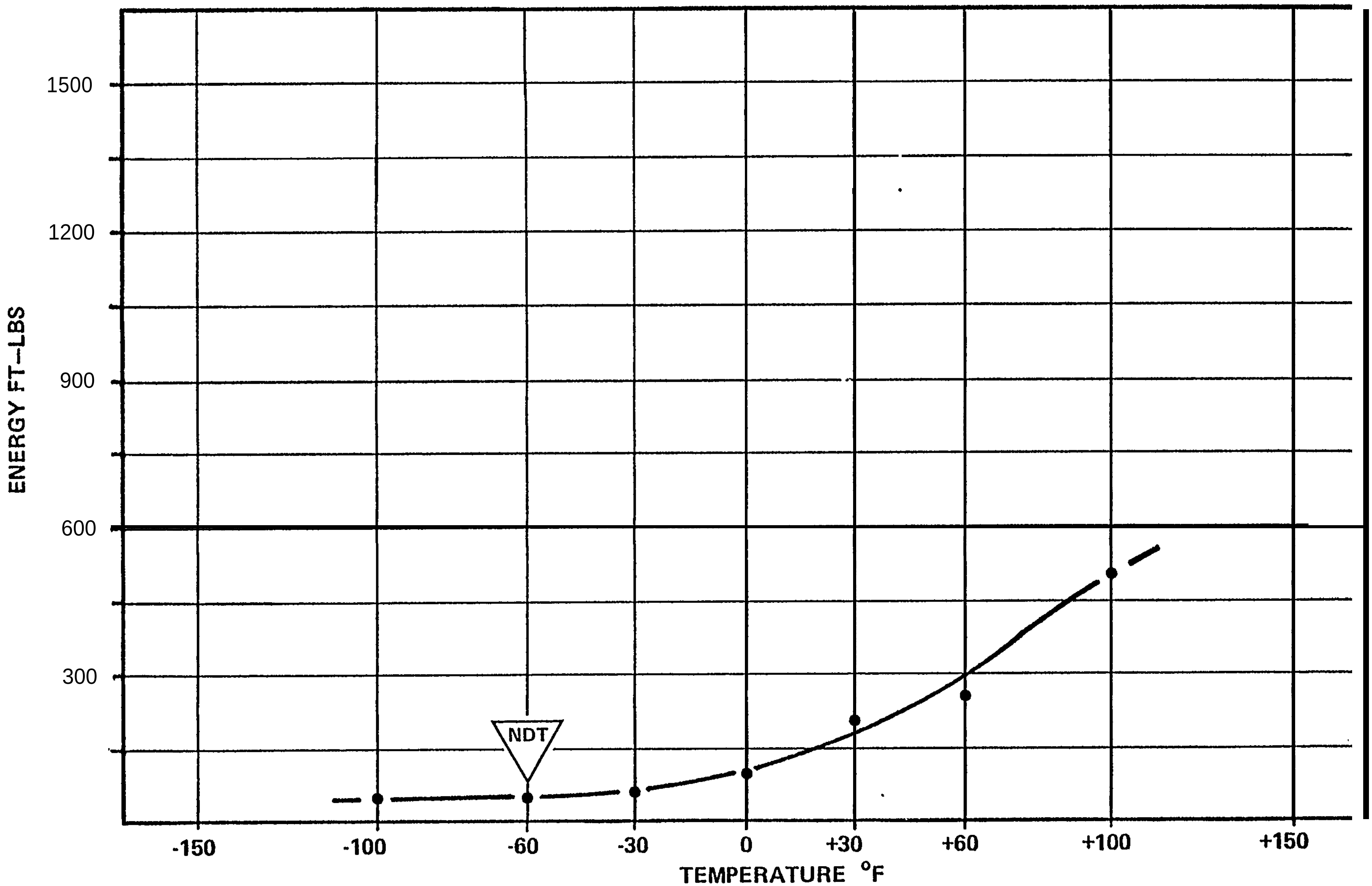
LINCOLN NR203 Ni @ 80 KJ/IN CHARPY V-NOTCH RESULTS FIG. 26



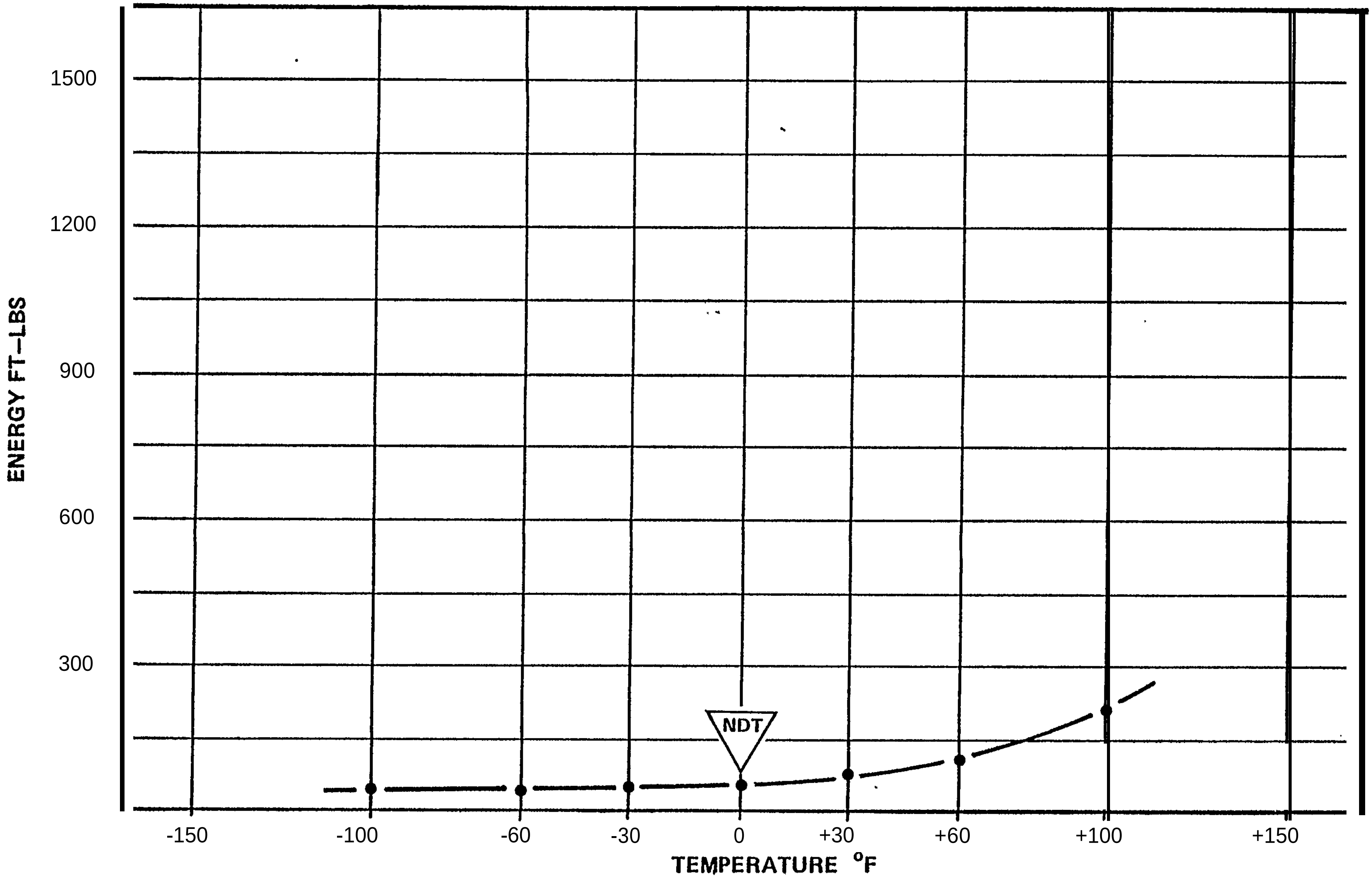
HOBART FABSHIELD 8 Ni @ 50 KJ/IN DYNAMIC TEAR RESULTS FIG. 27



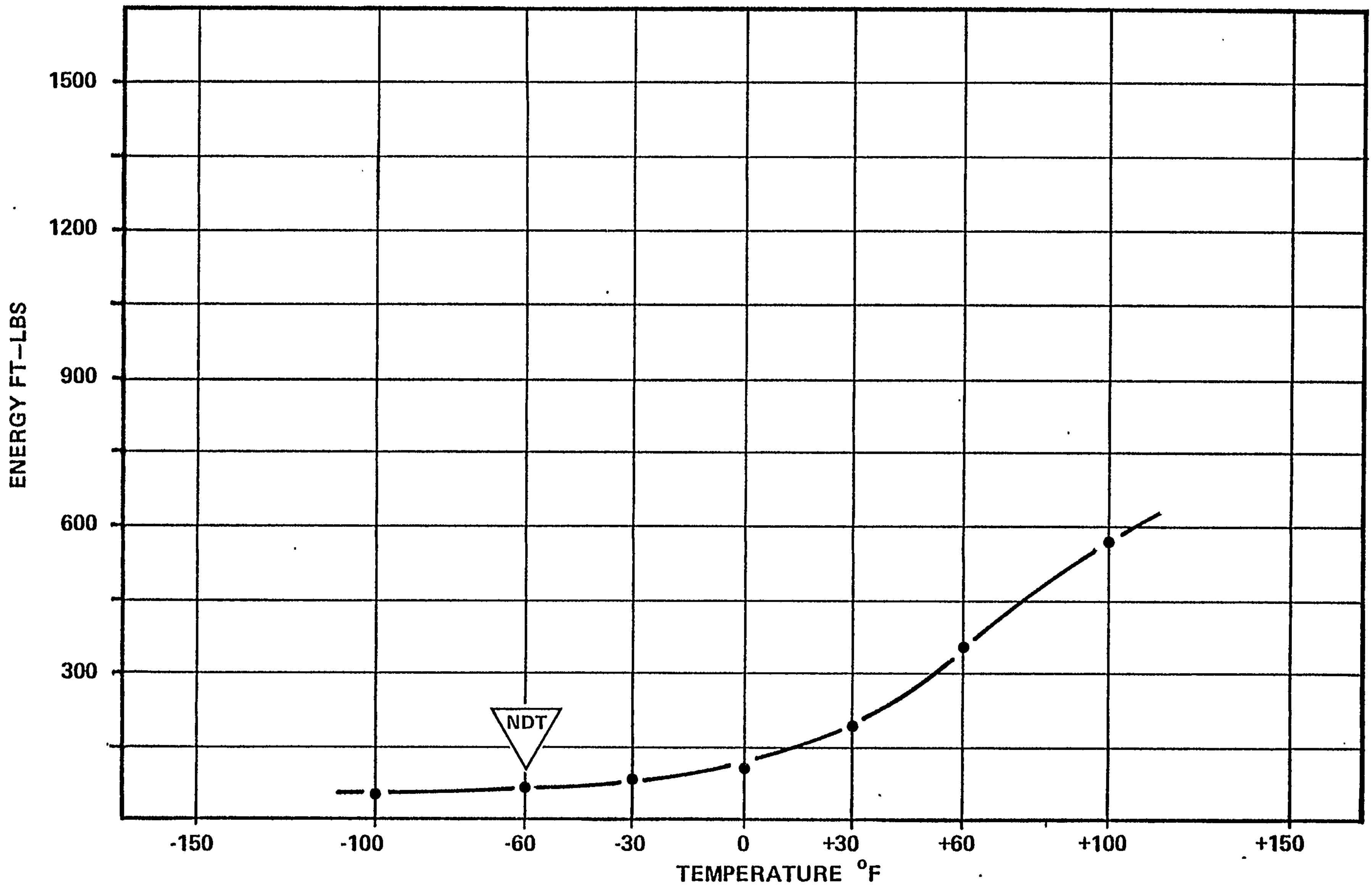
HOBART FABSHIELD 8 Ni @ 65 KJ/IN DYNAMIC TEAR RESULTS FIG. 28



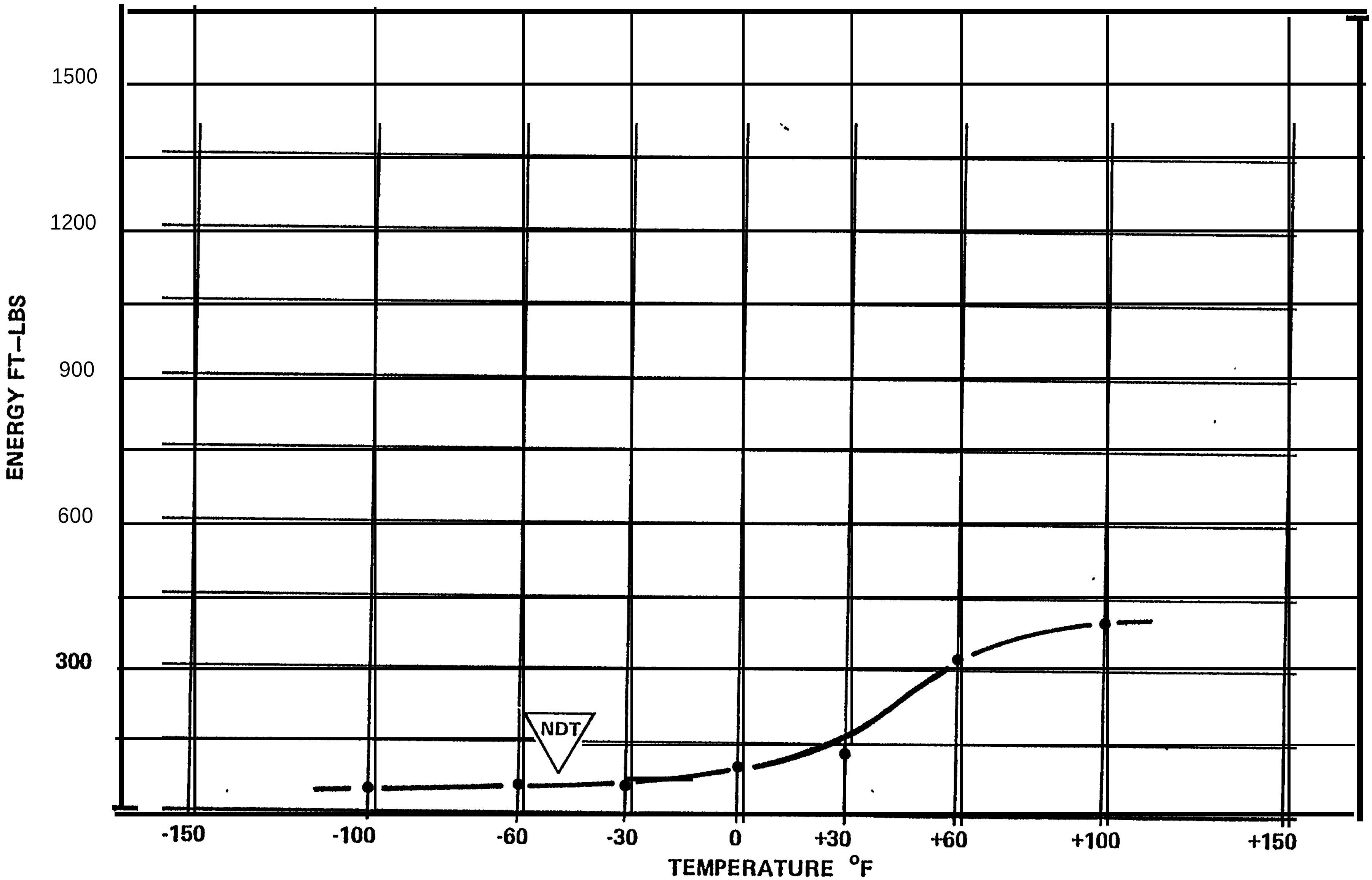
HOBART FABSHIELD 8 Ni @ 80 KJ/IN DYNAMIC TEAR RESULTS FIG. 29



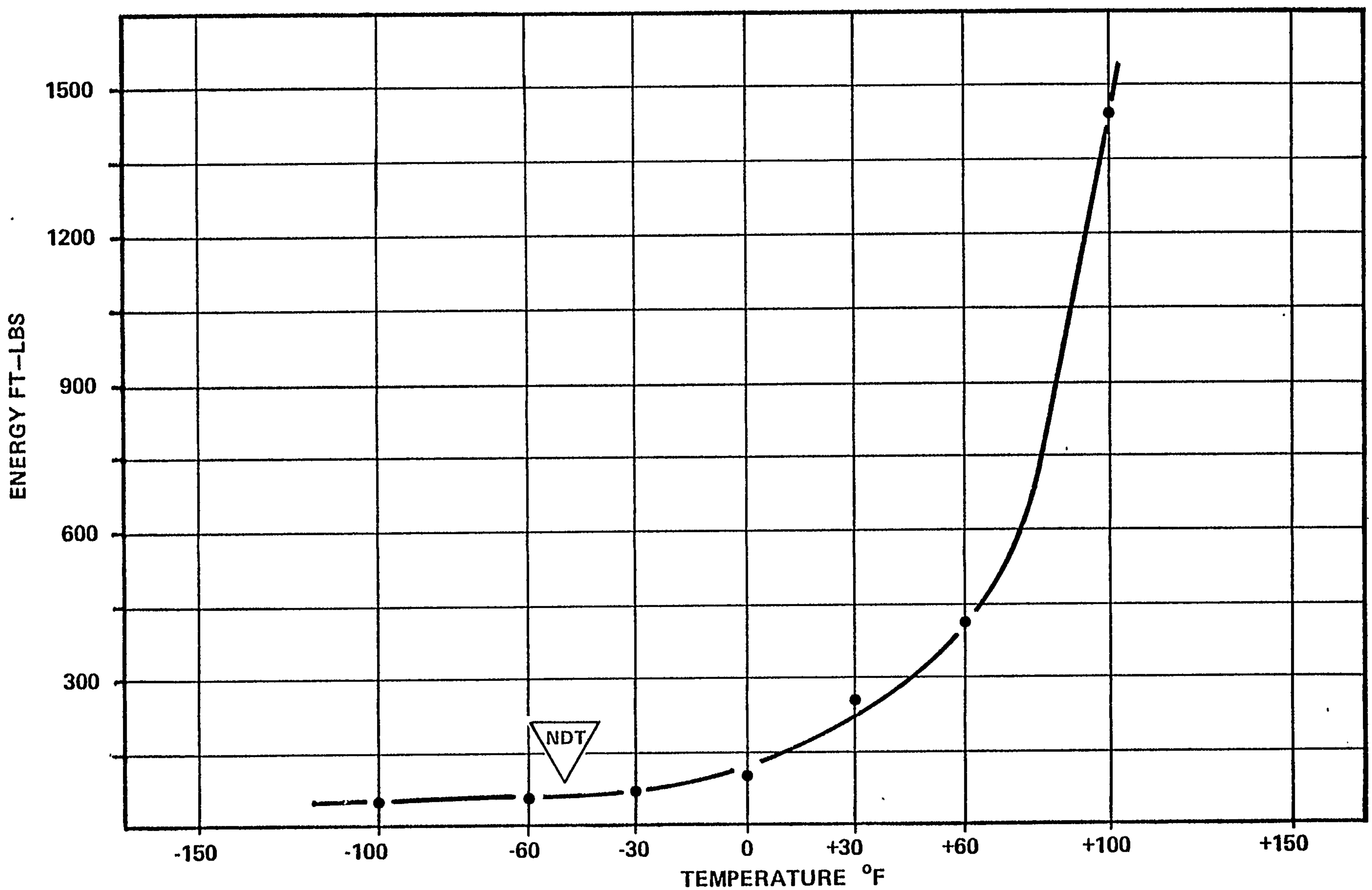
LINCOLN NR302 @ 50 KJ/IN DYNAMIC TEAR RESULTS FIG.30



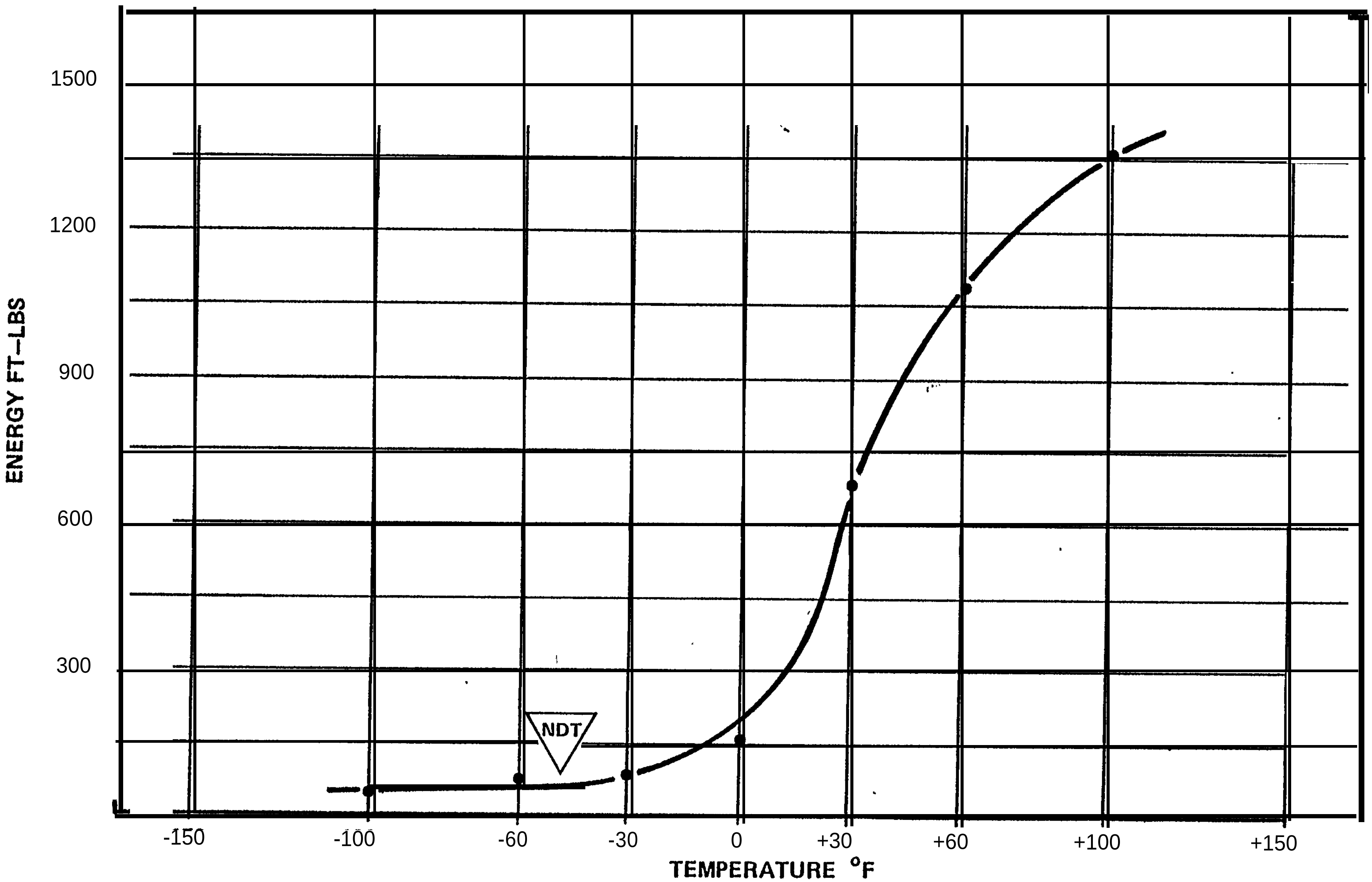
LINCOLN NR302 @ 65 KJ/IN DYNAMIC TEAR RESULTS FIG. 31



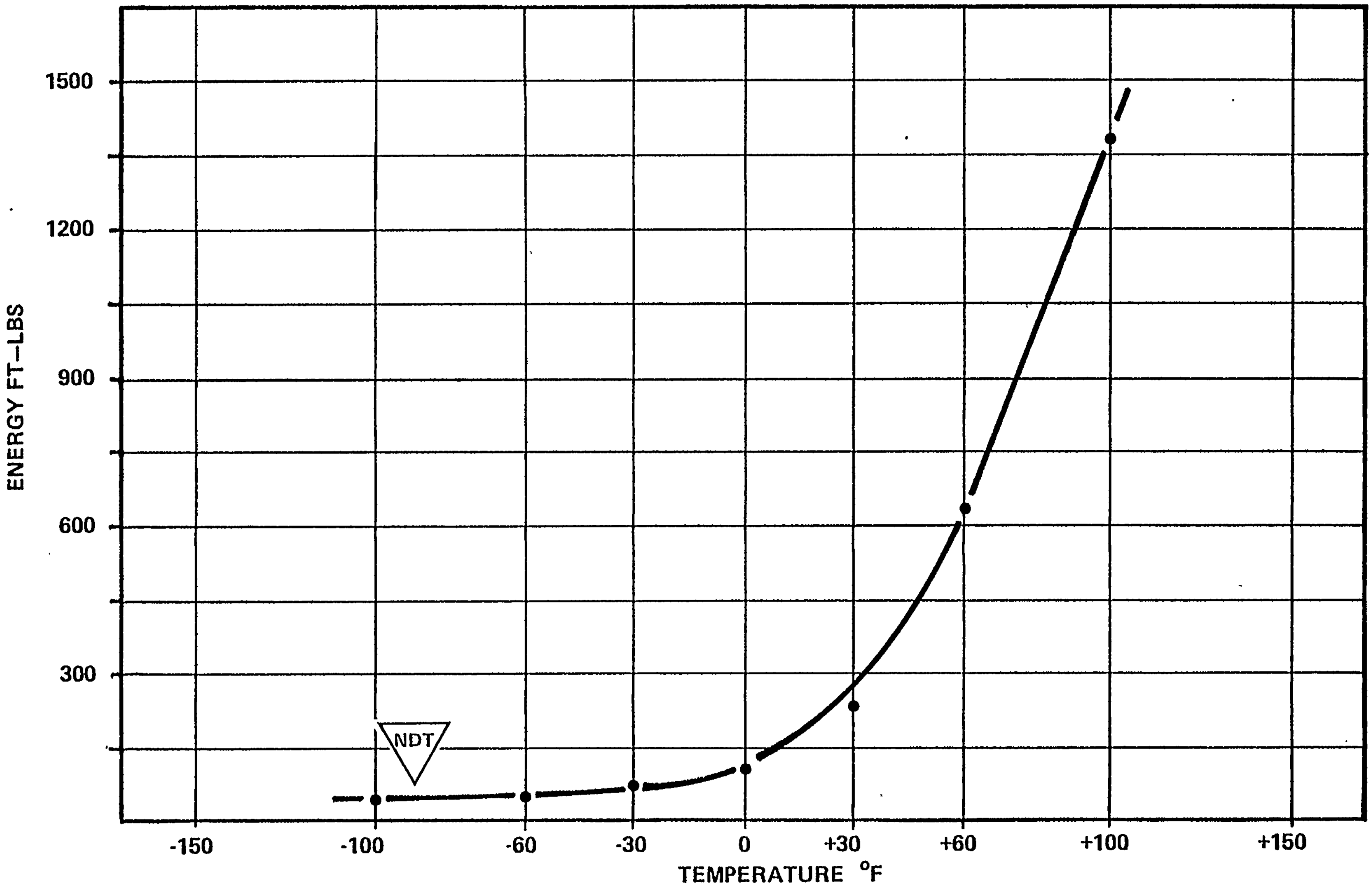
LINCOLN NR302 @ 80KJ/IN DYNAMIC TEAR RESULTS FIG.32



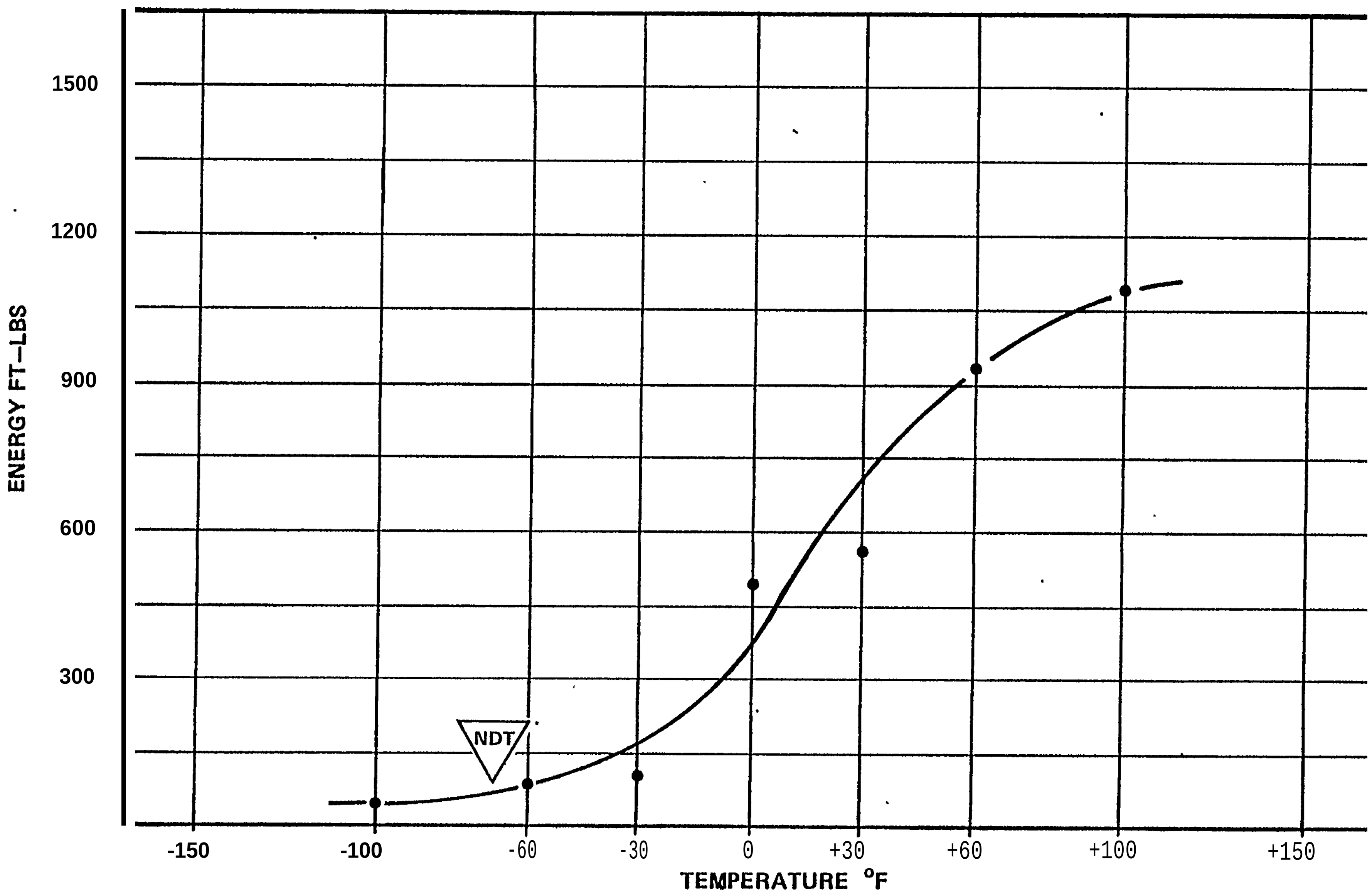
LINCOLN NR203M @ 50 KJ/IN DYNAMIC TEAR RESULTS FIG. 33



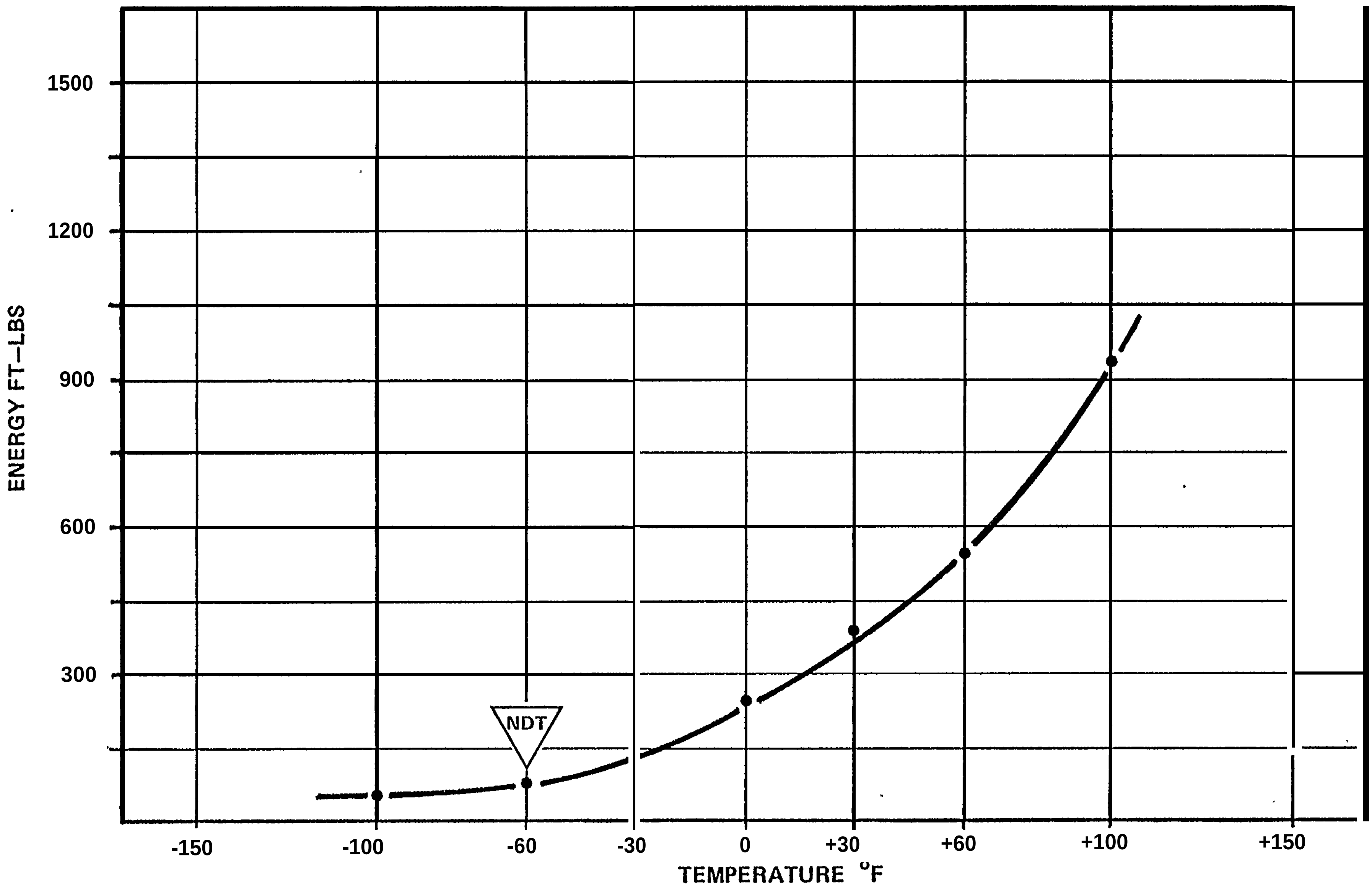
LINCOLN NR203M @ 65 KJ/IN DYNAMIC TEAR RESULTS FIG.34



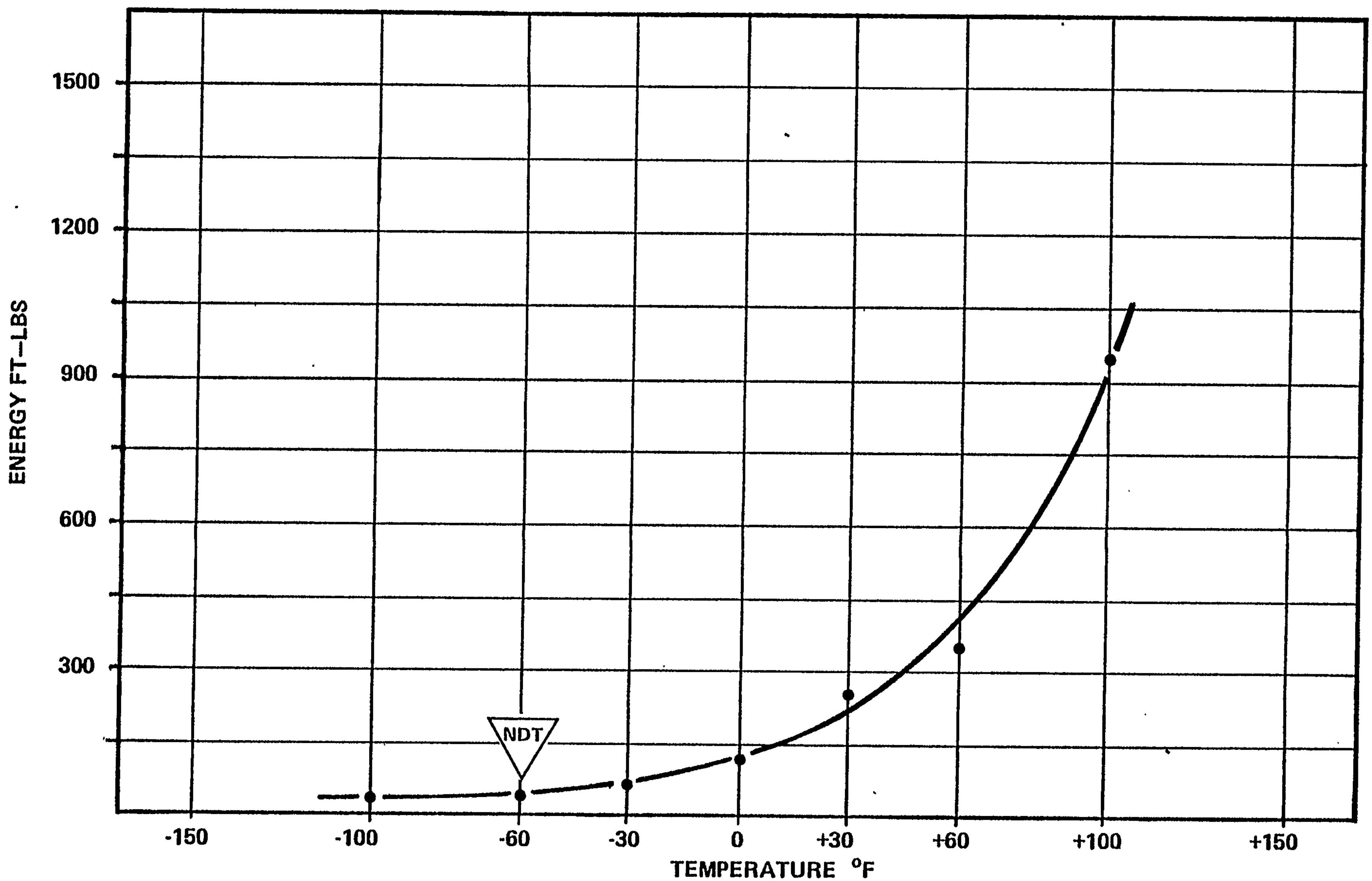
LINCOLN NR203M @ 80 KJ/IN DYNAMIC TEAR RESULTS FIG. 35



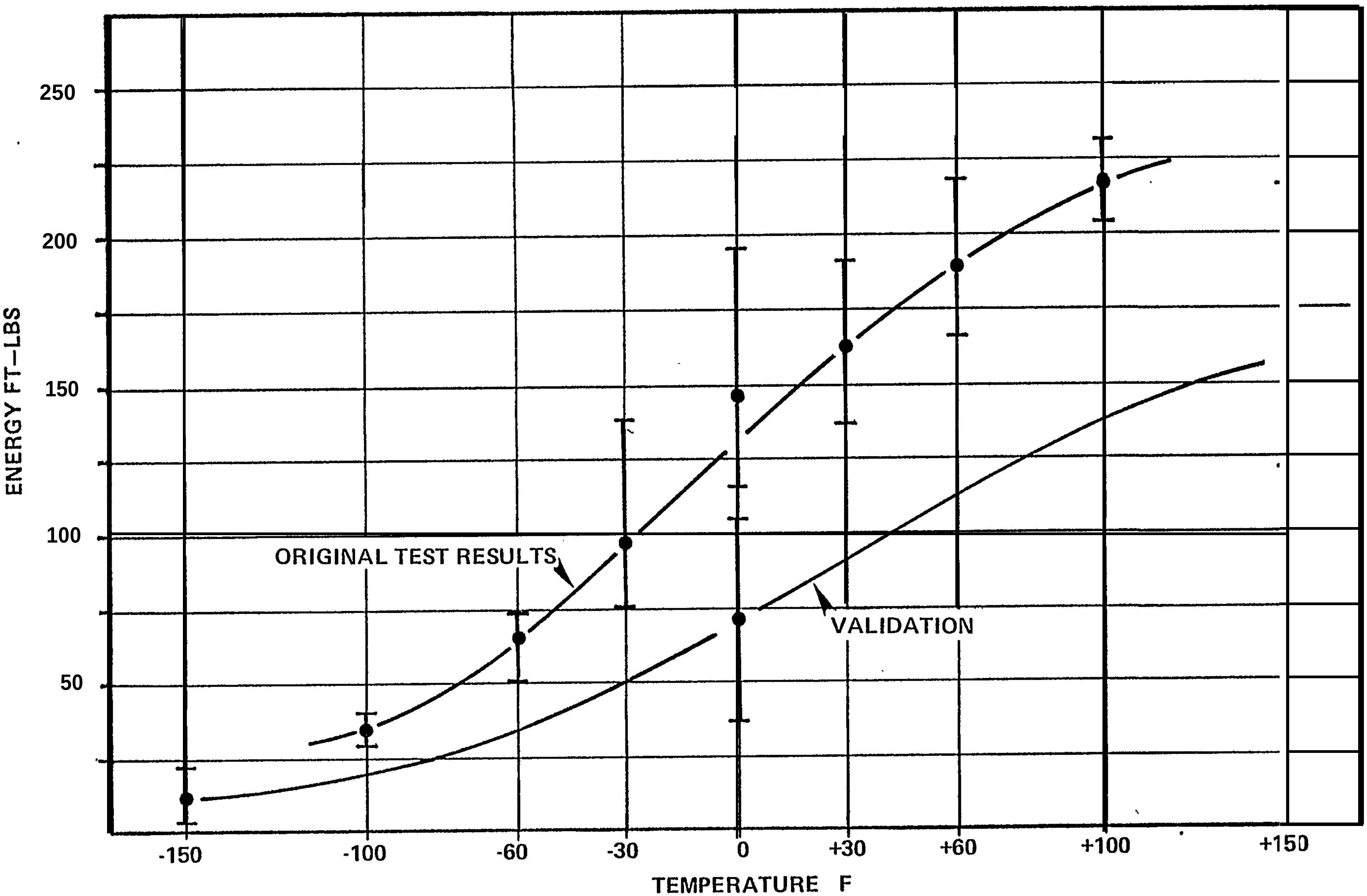
LINCOLN NR203 Ni @ 50 KJ/IN DYNAMIC TEAR RESULTS FIG. 36



LINCOLN NR203 Ni @ 65 KJ/IN DYNAMIC TEAR RESULTS FIG. 37

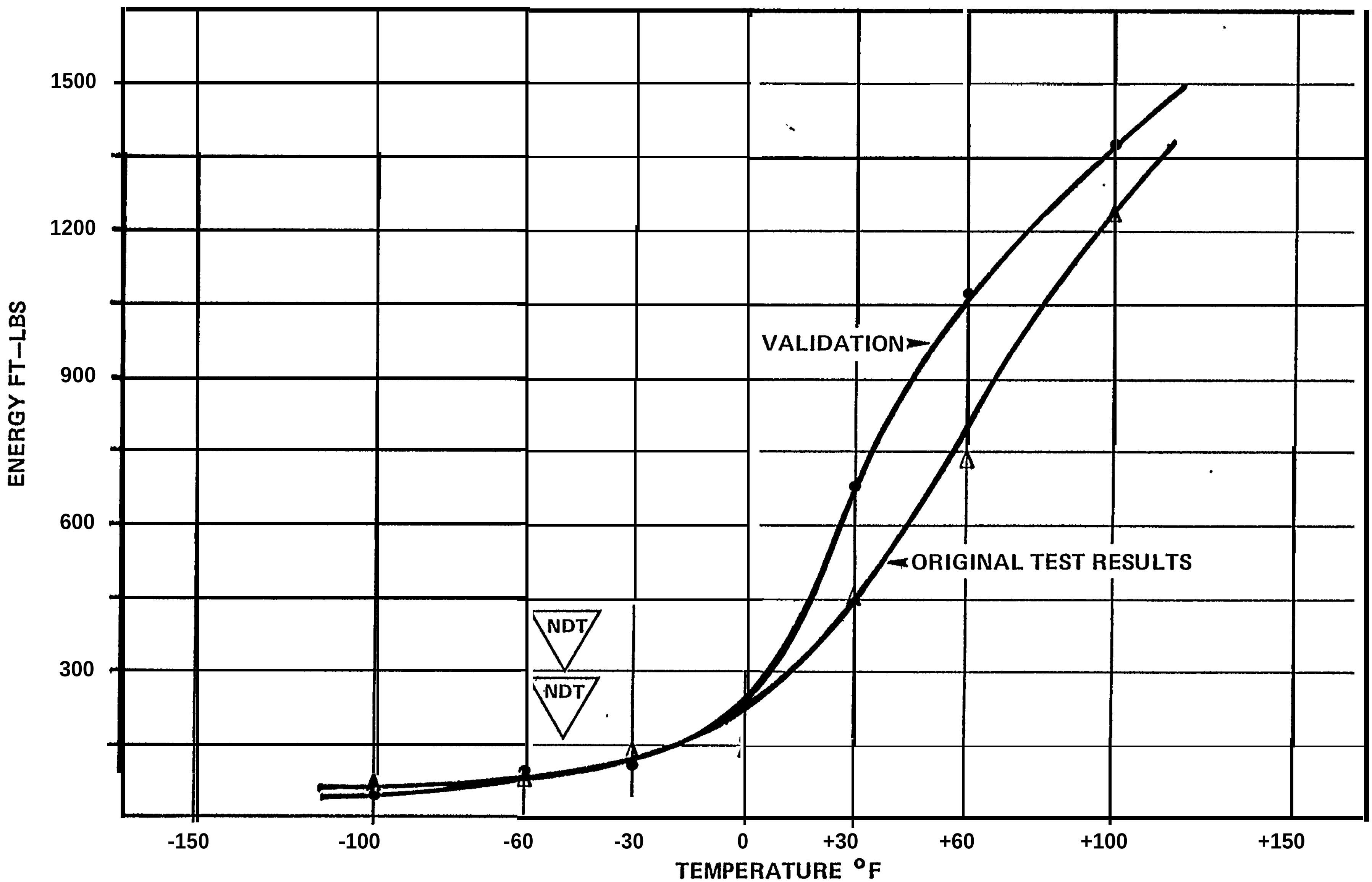


LINCOLN NR203 Ni @ 80 KJ/IN DYNAMIC TEAR RESULTS FIG. 38



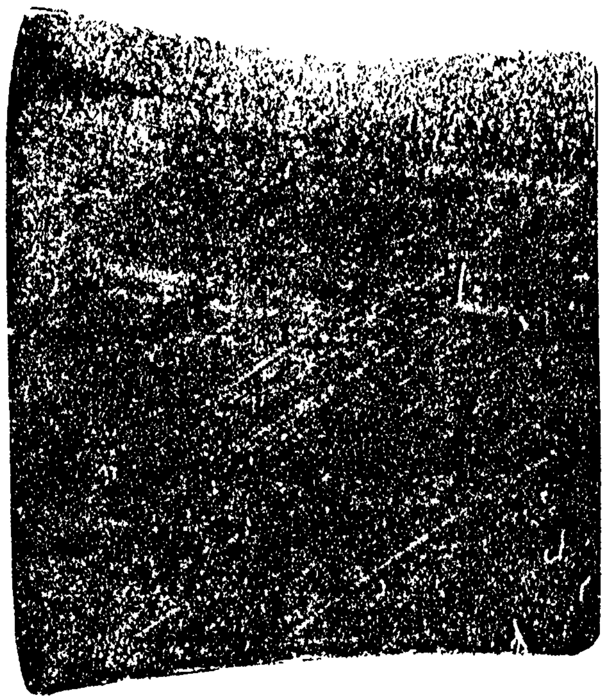
LINCOLN NR 203M @ 65 KJ/IN CVN ORIGINAL TEST VS VALIDATION TEST

FIG. 39

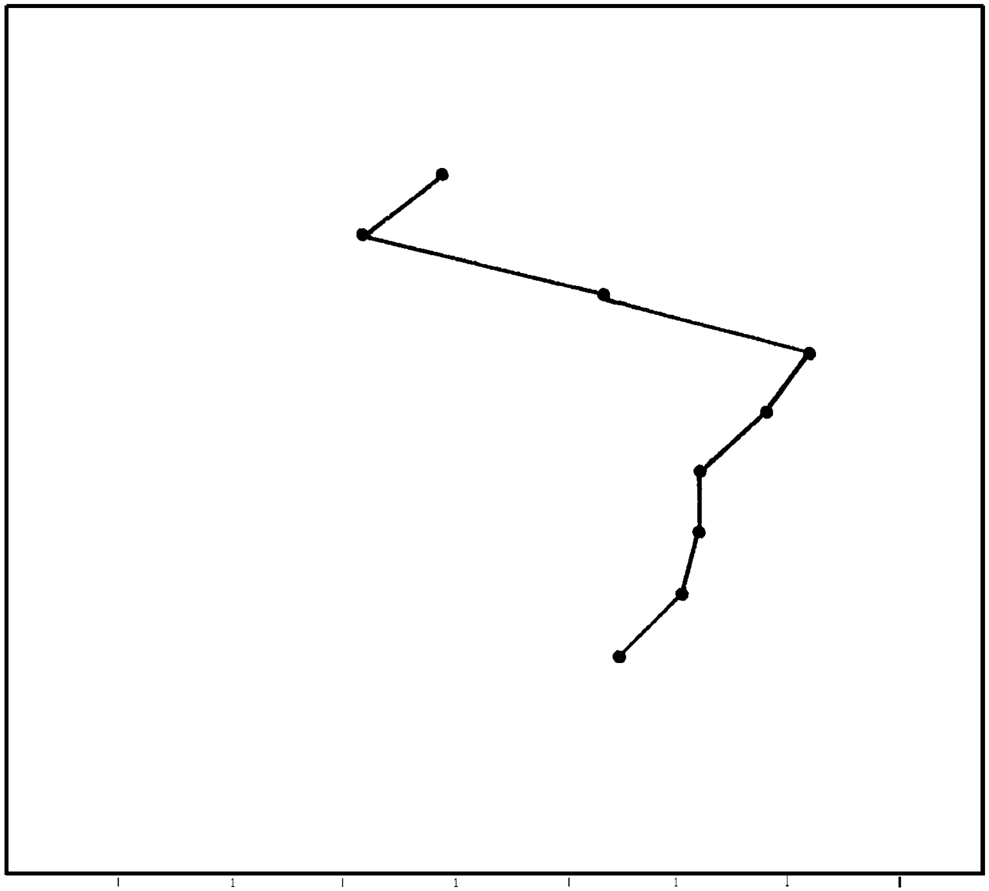


LINCOLN NR 203M @ 65 KJ/IN DT ORIGINAL TEST VS. VALIDATION TEST

FIG. 40



CVN @ 0 °F 7.5x

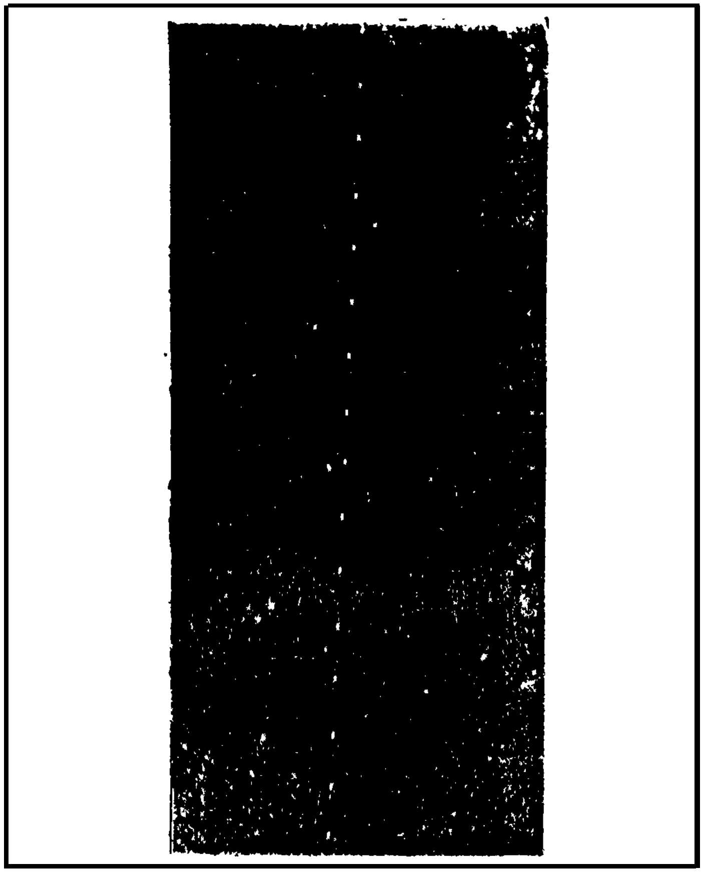


Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
73.9	61.7	31.5	74.6	87.6	77.2	273.7	73.3	73.6	75.5

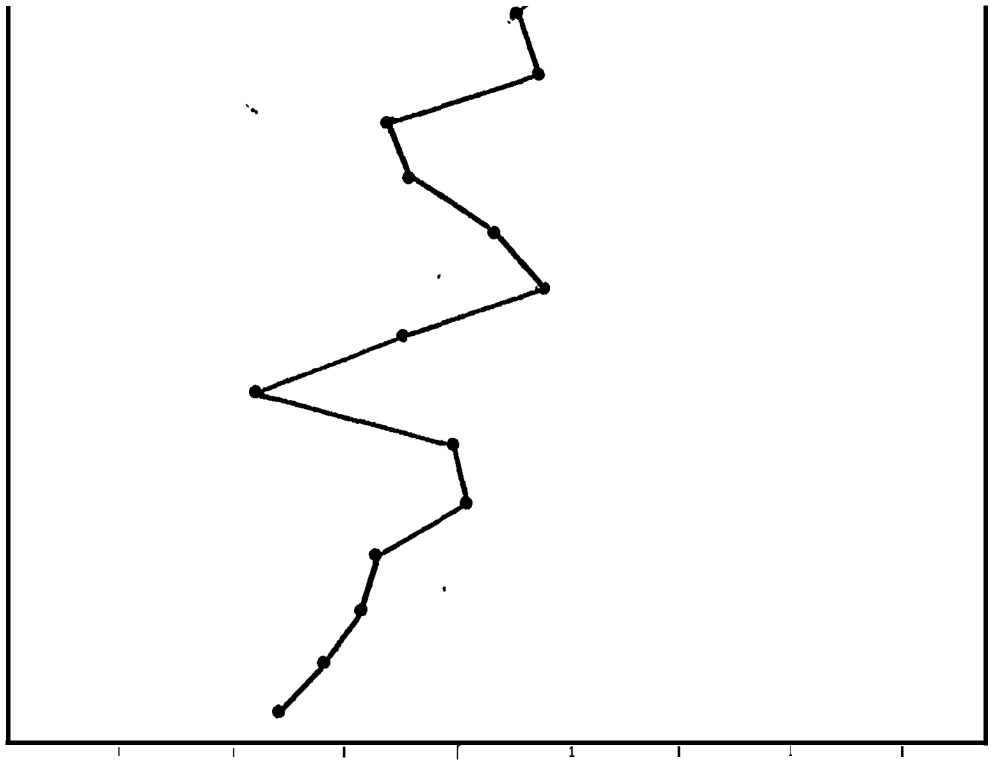
NOTE: All Values are Averages

LINCOLN NR 203M @ 50 KJ/IN CVN KNOOP HARDNESS TRAVERSE

FIG. 41



DT@O°F 7x

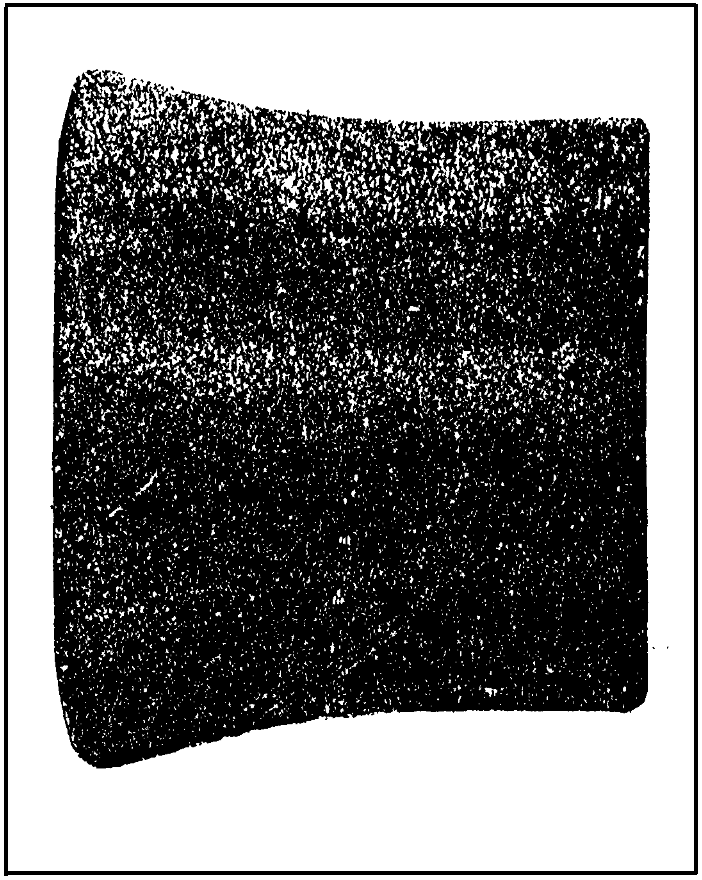


Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% R A	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
73.9	61.7	31.5	74.6	87.6	77.2	237.6	87.6	77.2	106

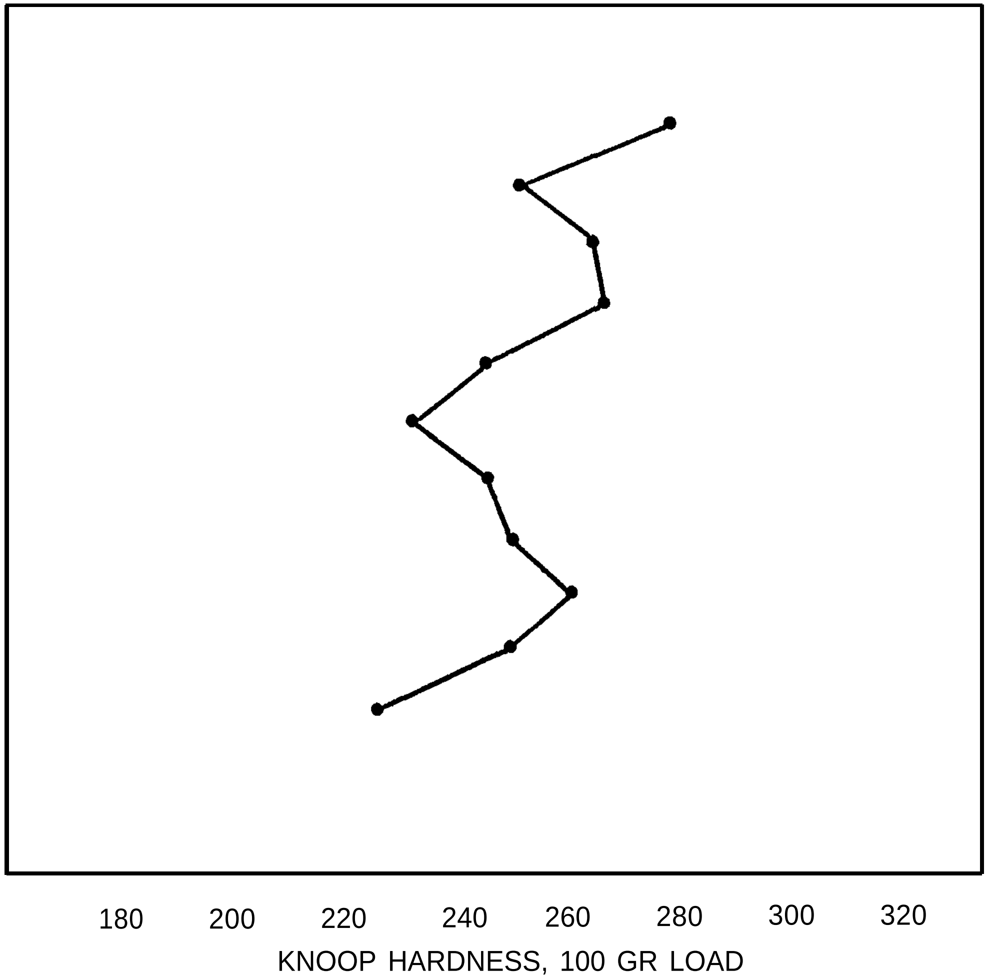
NOTE: All Values are Averages

LINCOLN NR 203M @ 50 KJ/IN DT KNOOP HARDNESS TRAVERSE;

FIG. 42



CVN @ 0 °F 7.5x

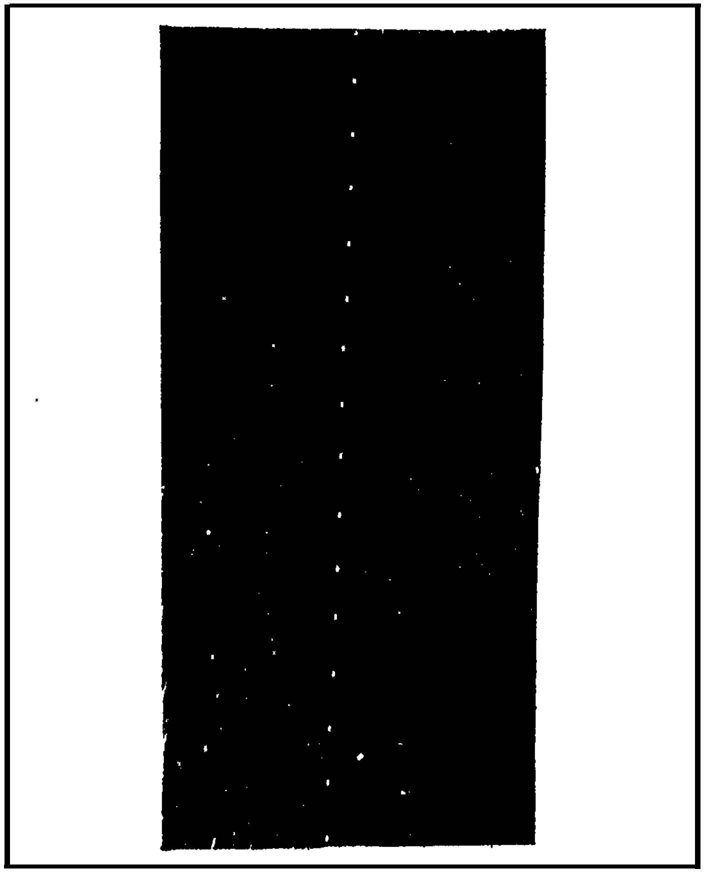


Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
68.3	58.1	32.5	75.9	86.8	73.2	251.6	89.7	87.8	145

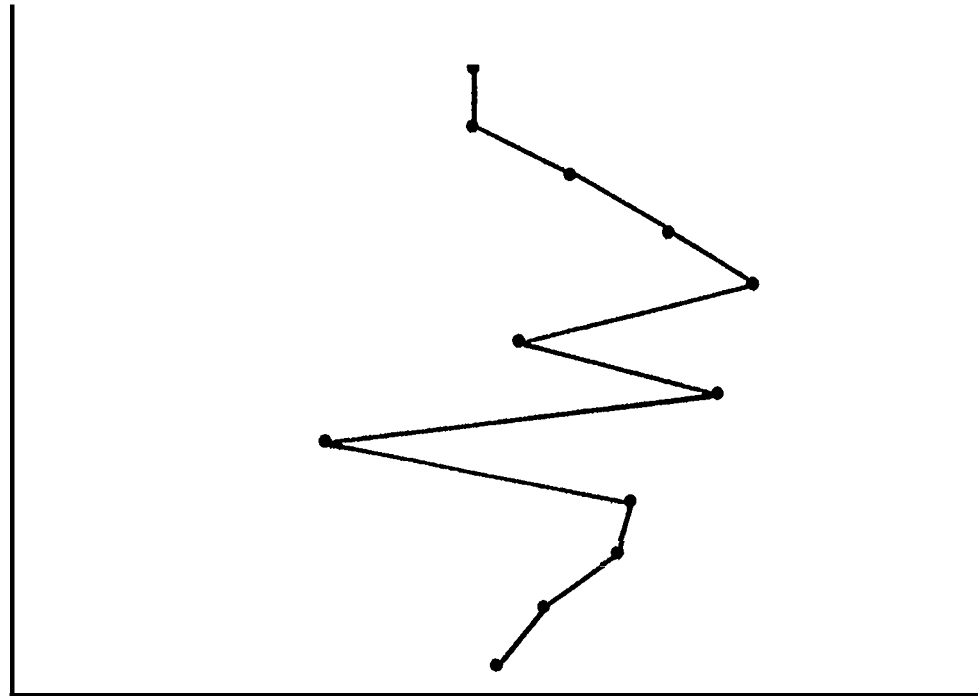
NOTE: All Values are Averages

LINCOLN NR 203M @ 65 KJ/IN CVN KNOOp HARDNESS TRAVERSE

FIG. 43



DT@O°F 7x

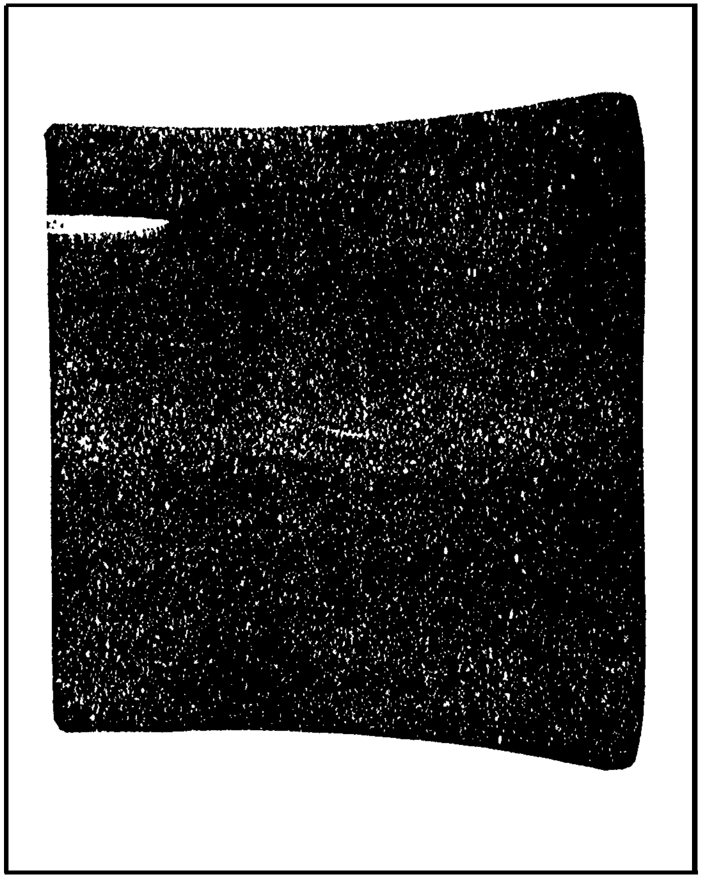


Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
68.3	58.1	32.5	75.9	86.8	73.2	252.8	87.8	77.6	252

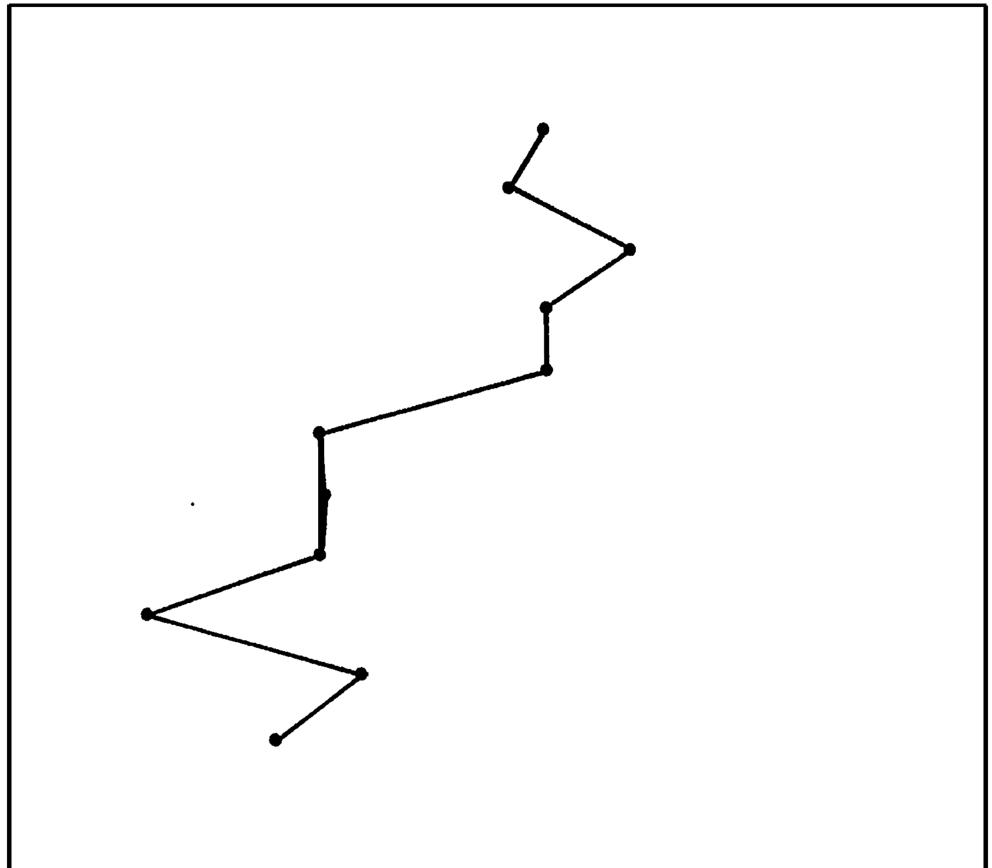
NOTE: All Values are Averages

LINCOLN NR 203M @ 65 KJ/IN DT KNOOP HARDNESS TRAVERSE

FIG. 44



CVN@O°F 7.5x

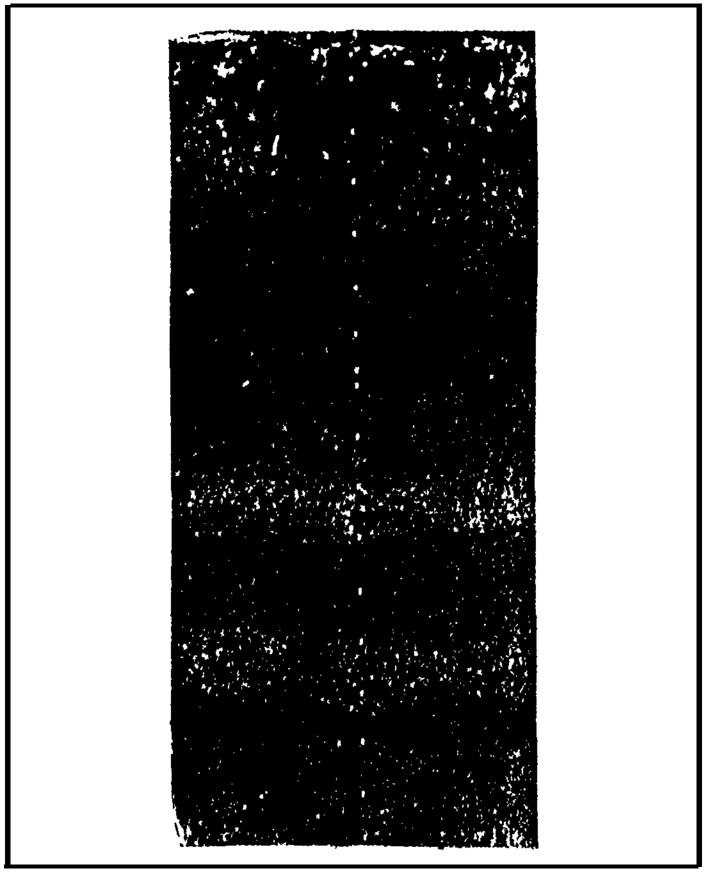


Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
69.6	54.1	34.0	76.7	87.2	75.2	231.6	89.2	84.6	71.3

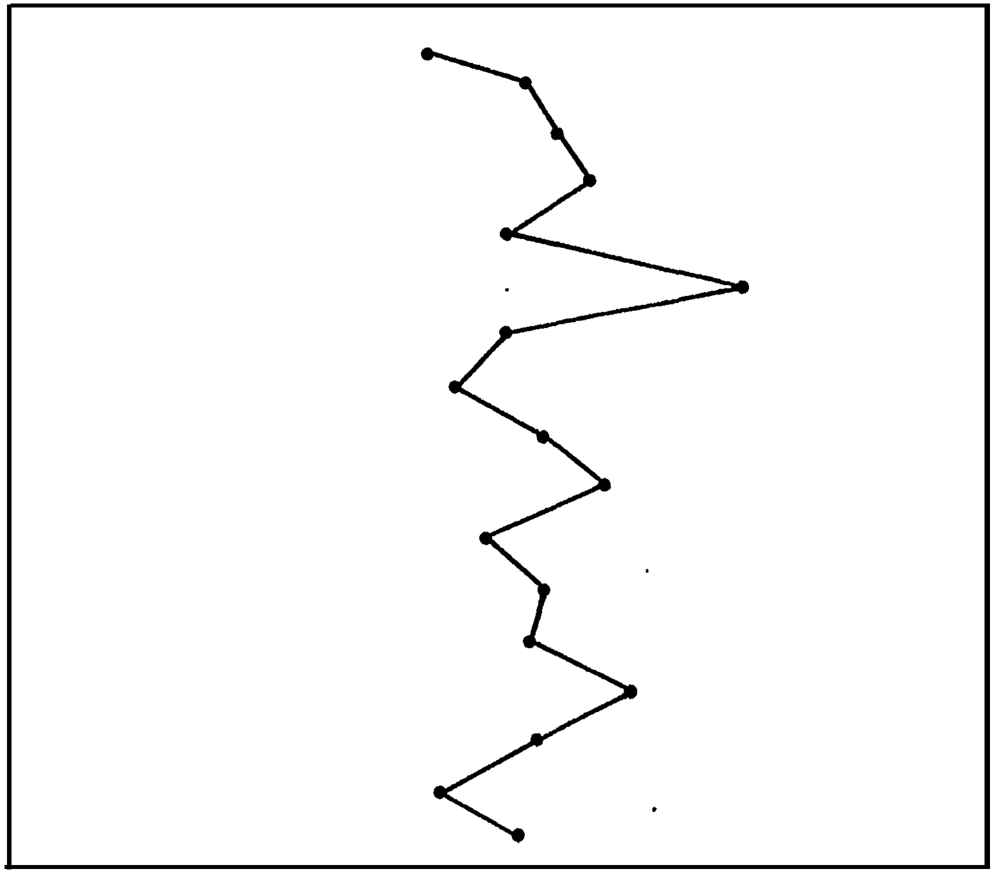
NOTE: All Values are Averages

LINCOLN NR 203M @ 80 KJ/IN CVN KNOOP HARDNESS TRAVERSE

FIG. 45



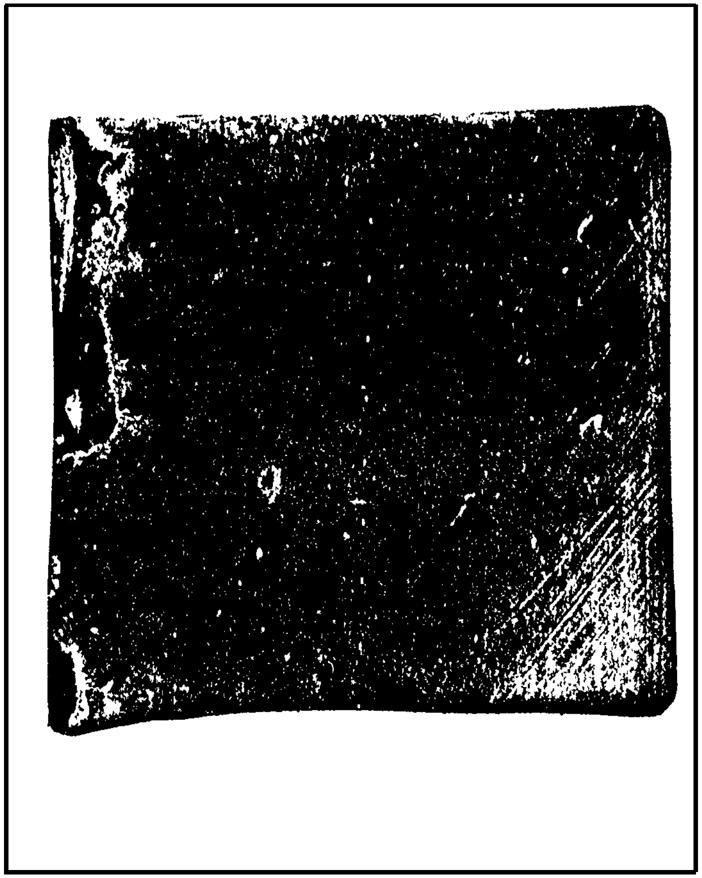
DT@O°F 7 x



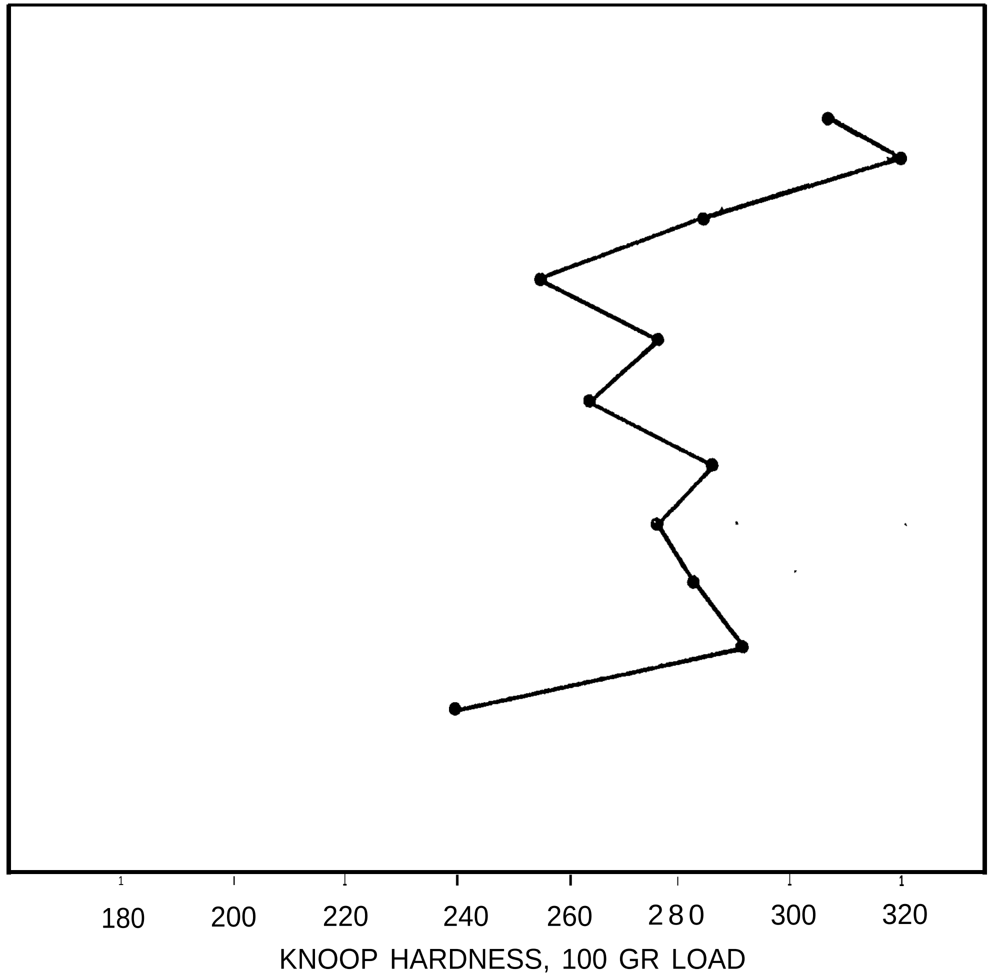
Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
69.6	54.1	34.0	76.7	87.2	75.2	253.6	87.1	73.7	117

NOTE: All Values are Averages

LINCOLN NR 203M @ 80 KJ/IN DT KNOOP HARDNESS TRAVERSE FIG. 46



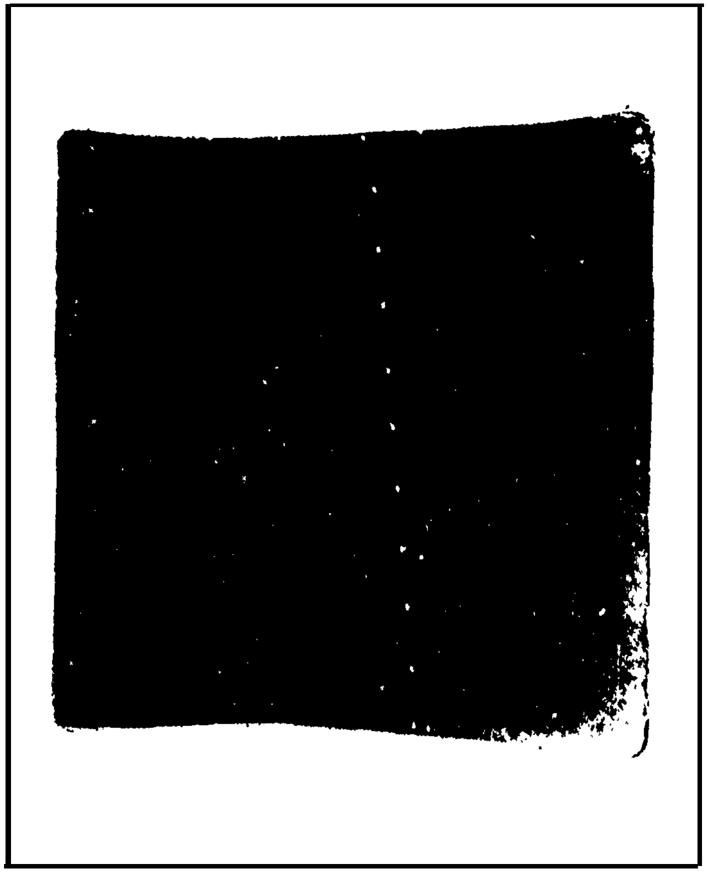
CVN @ 0 °F 7.5x



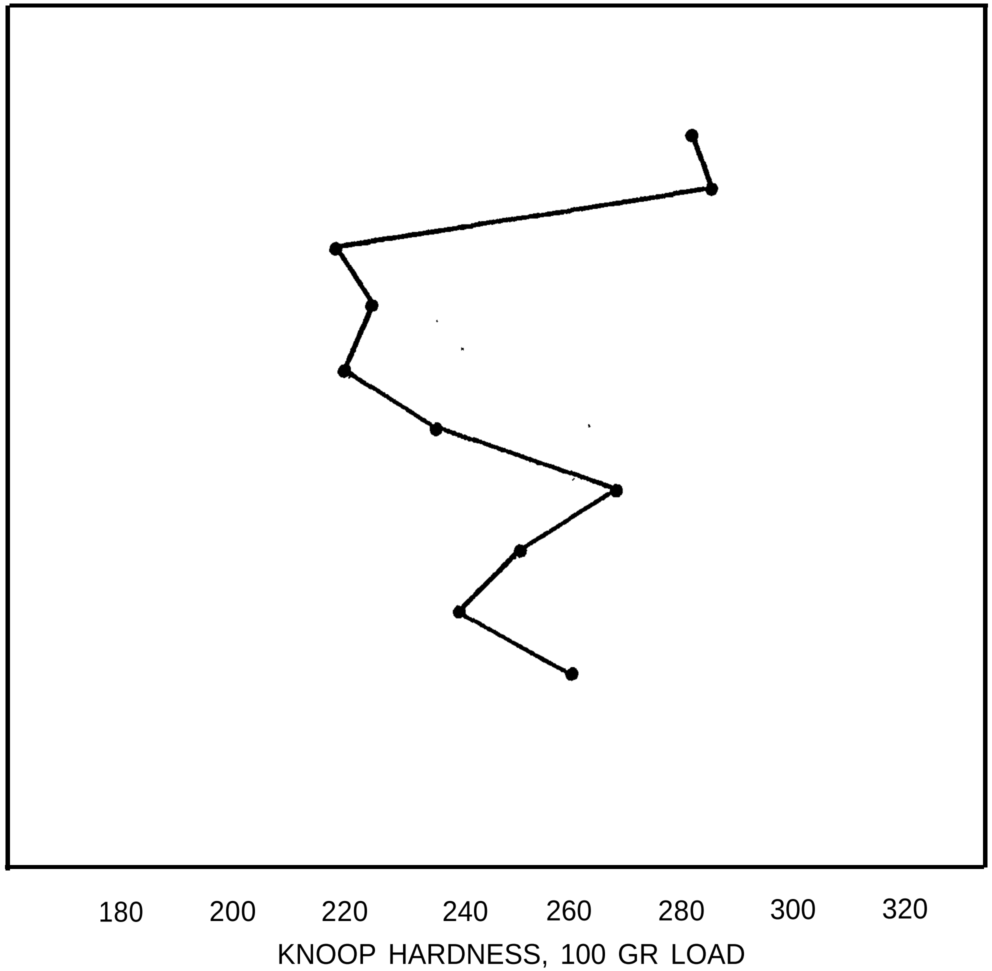
Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
94.3	77.6	22.5	68.8	89.4	86.2	288.9	**82.3**	—	19.7

NOTE: All Values are Averages

HOBART FABSHIELD 8 Ni @ 65 KJ/IN CVN KNOOP HARDNESS TRAVERSE FIG. 47



CVN @ 0 °F 7.5X

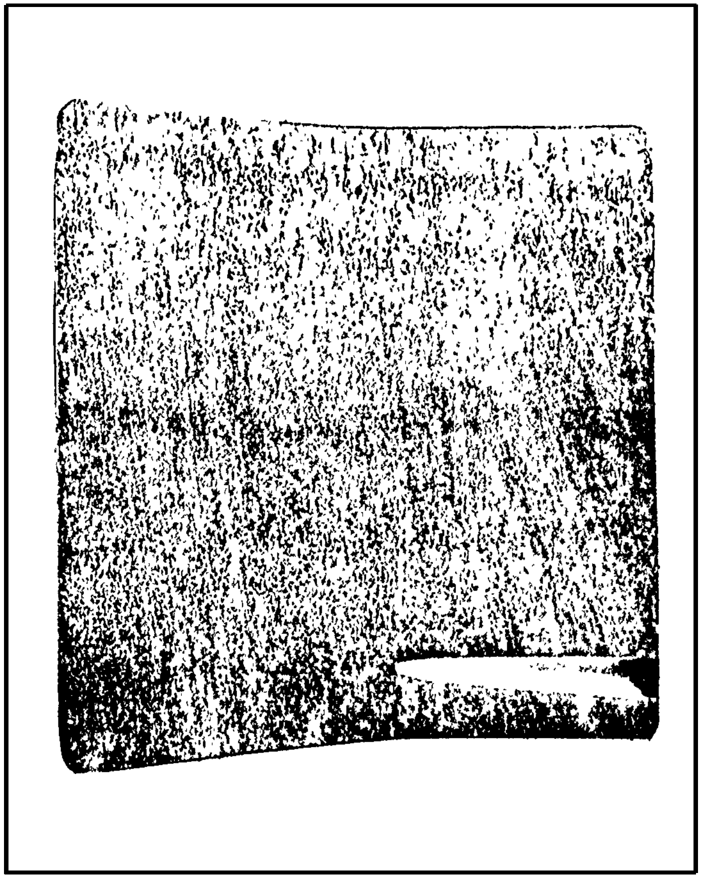


Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R. 15T	Tensile KSI	Ft/lbs
74.1	61.1	29.5	67.4	87.2	75.2	248.8	88.1	78.6	36.0

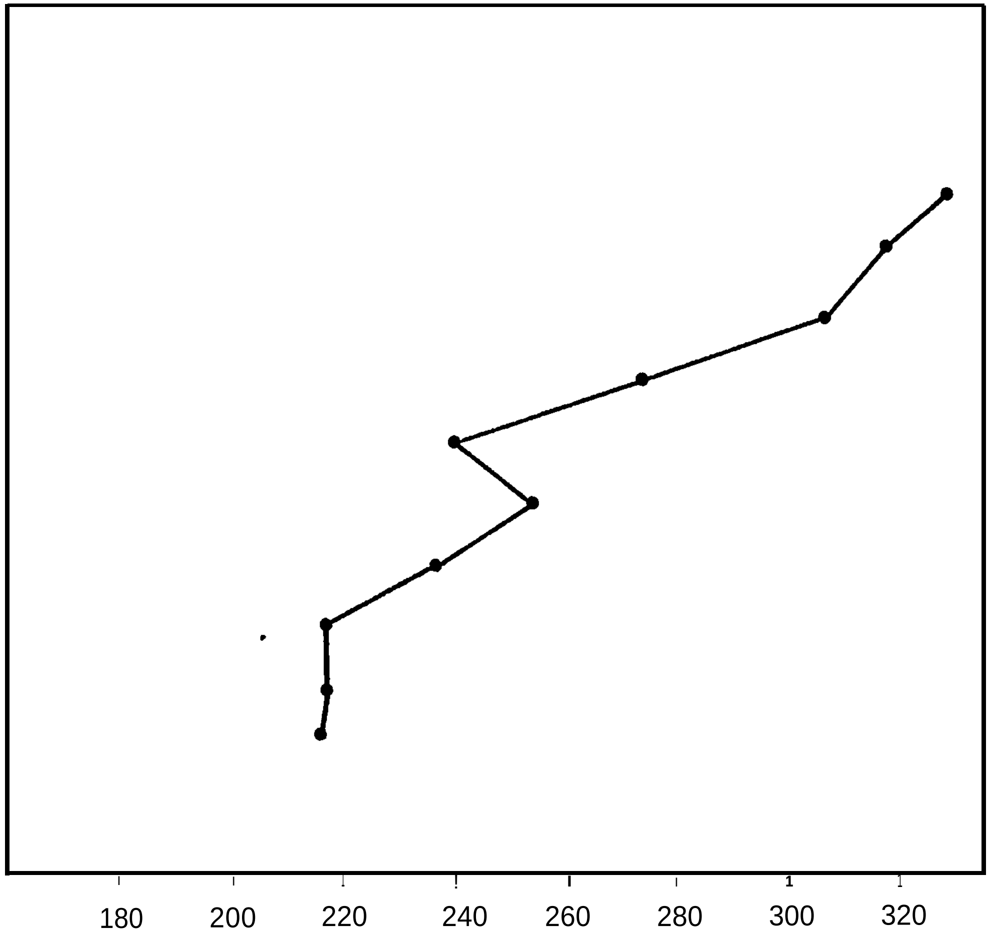
NOTE: All Values are Averages

LINCOLN NR 302 @ 65 KN/IN CVN KNOOP HARDNESS TRAVERSE

FIG. 48



CVN @ 0 °F 7.5x



Actual Mechanical Results KSI				Hardness Traverse of Macro		Hardness Traverse of Specimen			Toughness
Tensile	Yield	% Elong	% RA	R 15T	Tensile KSI	KH	R 15T	Tensile KSI	Ft/lbs
73.8	58.7	35.0	72.5	89.0	83.0	271.0	89.5	87.0	82,3

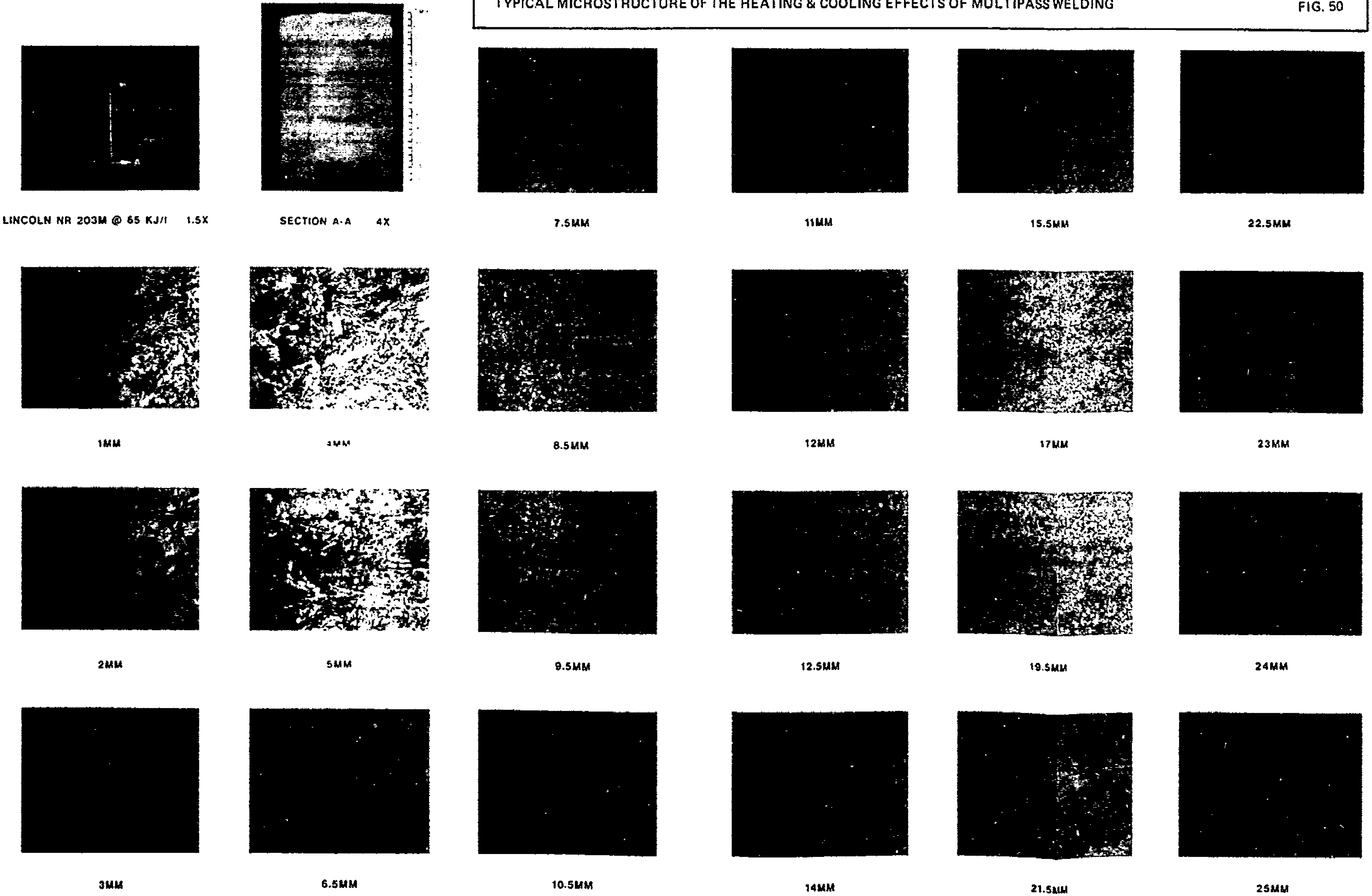
NOTE: All Values are Averages

LINCOLN NR 203 Ni @ 65 KJ/IN CVN KNOOP HARDNESS TRAVERSE

FIG. 49

TYPICAL MICROSTRUCTURE OF THE HEATING & COOLING EFFECTS OF MULTIPASS WELDING

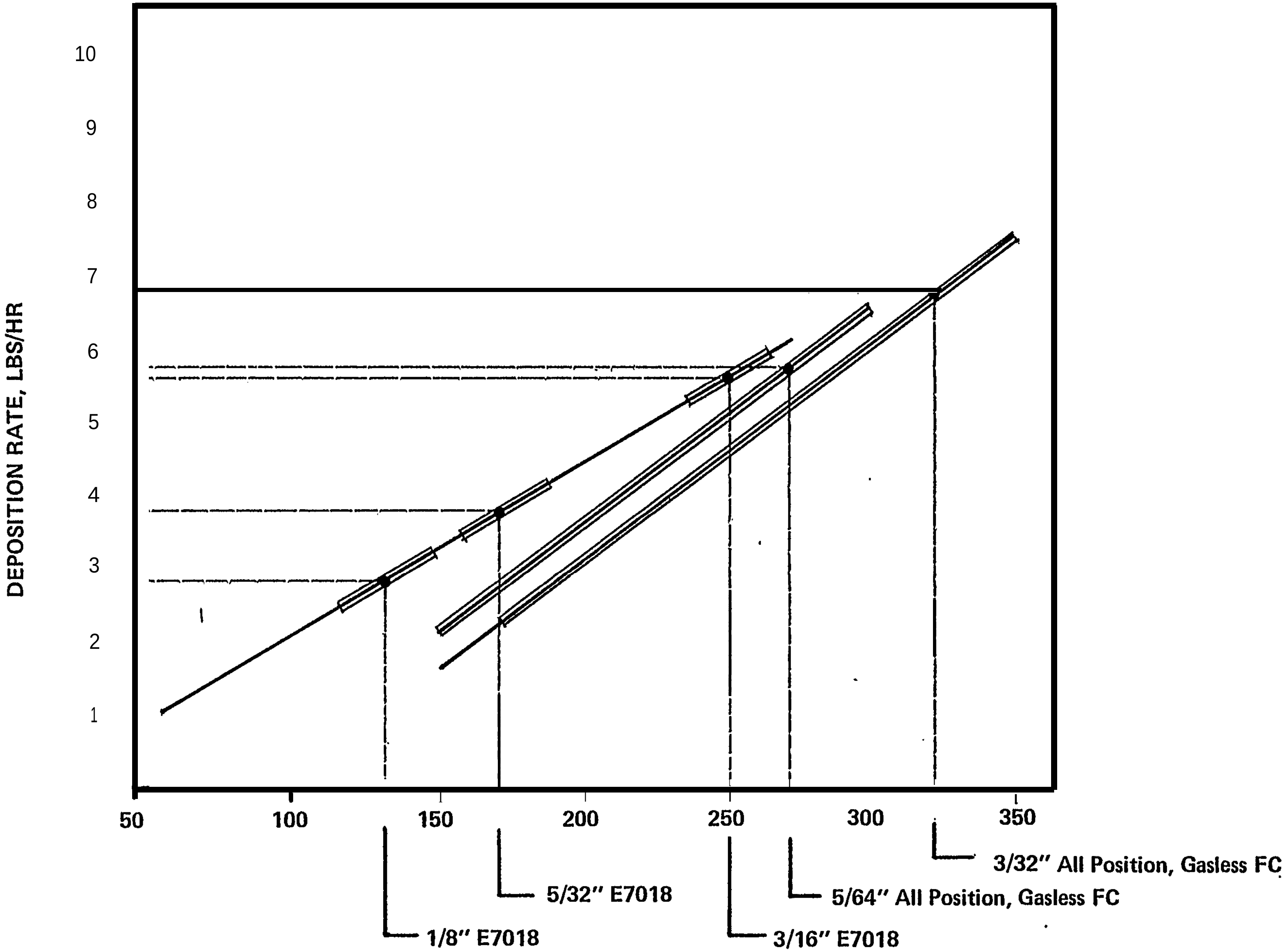
FIG. 50



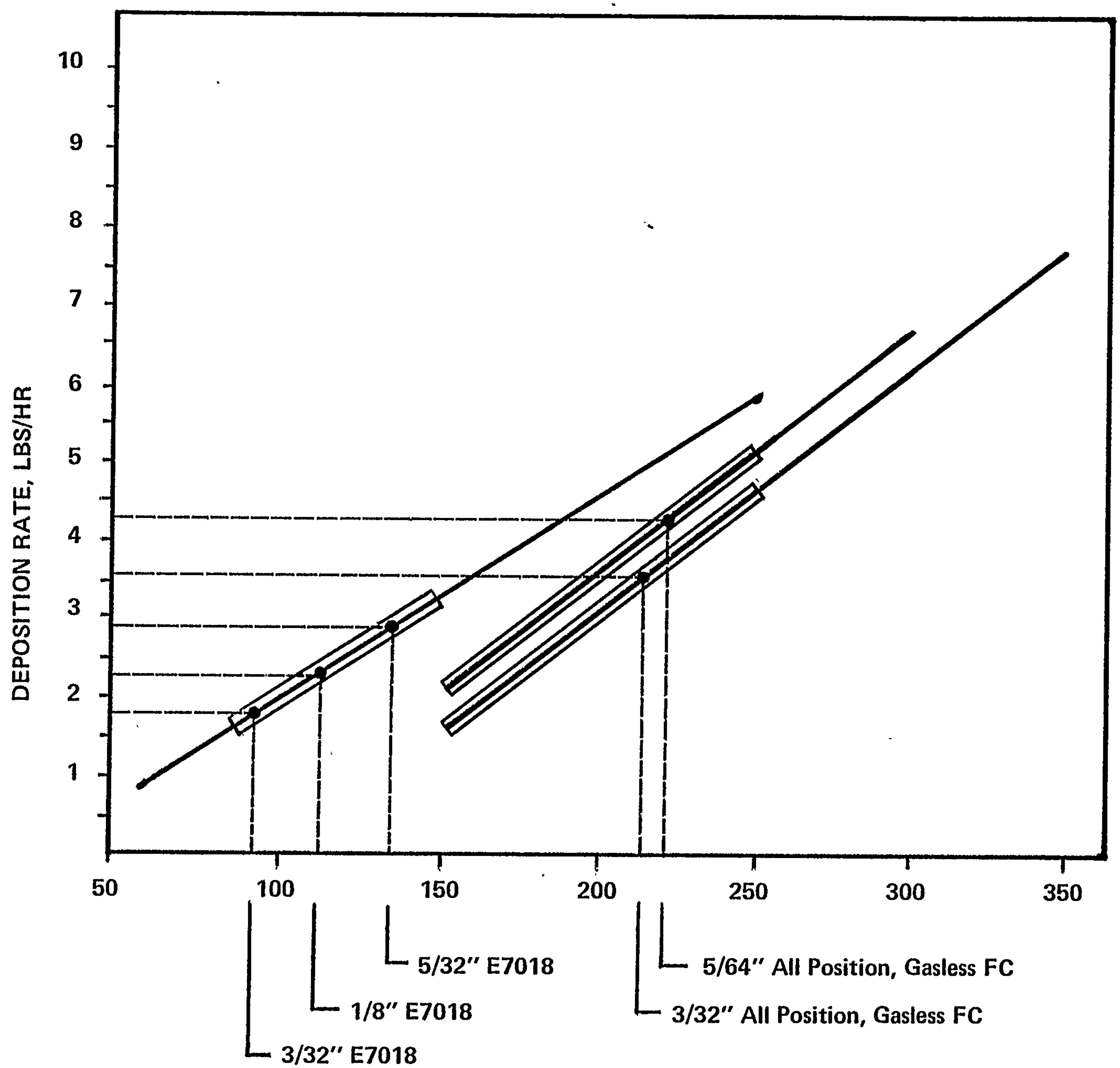
APPENDIX III

PHASE III

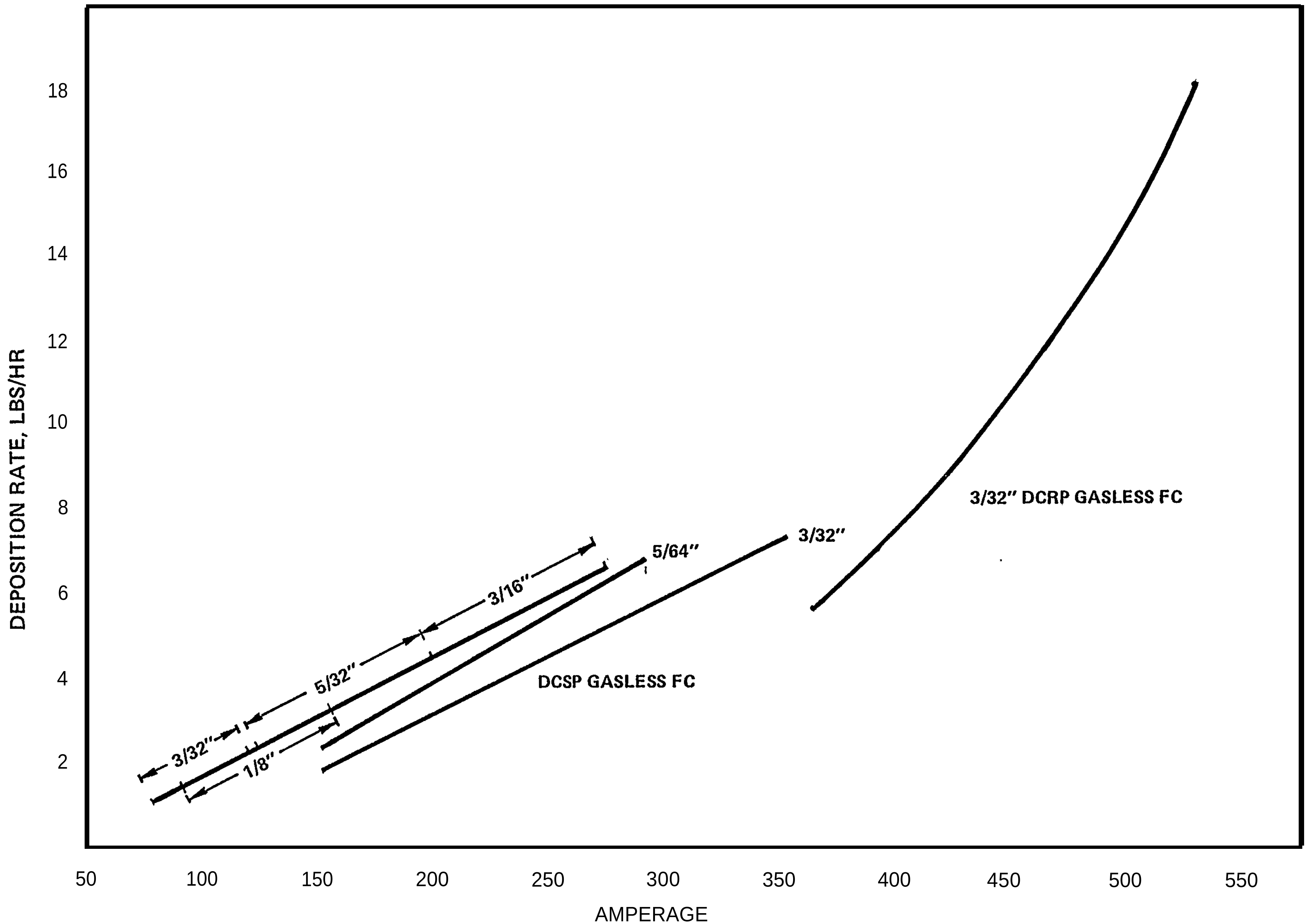
Tables & Figures



TYPICAL AMPERAGES USED FOR FLAT POSITION WELDING FIG. 51



TYPICAL AMPERAGES USED FOR VERTICAL UP WELDING FIG. 52



E7018 SMAW ELECTRODES VS. GASLESS FLUX-CORED WIRES FIG.53